

Preliminary Measurement of Welding Fumes in Automotive Plants

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Abstract—The preliminary measurement of welding fumes was conducted by means to get firsthand experience and understanding the welding fumes issues in automotive assembly plant in Malaysia. Personal sampling pumps were provided to a human welder of highest risk in the assembly section. Series of direct reading measurement for area sampling of particulate matters 2.5µm or less in diameter size (P.M_{2.5}), toxic gases and temperature were also conducted at the same time. The welding fumes sample were then analyze by scanning electron microscope with energy dispersive spectroscopy (SEM-EDS). Questionnaires were distributed to the welders for questionnaire’s pilot test purpose in order to determine welder’s knowledge on welding hazards and persistent symptom experience by each welder. Results of the study show that welding fumes contains the highest element of cobalt and nickel. Carbon monoxide (CO), carbon dioxide (CO₂) and ammonia level were well below the standard level. Results from the mean score questionnaire analysis shows the welders posses limited knowledge of welding fumes hazard and not sure of the health effects of welding fumes There are eight persistent symptoms that had been experience by at least 50% of the welder. This preliminary study had successfully identified suggestion and alteration towards the actual measurement that will be conduct on the next stage.

Index Terms—Health symptoms, preliminary measurement, questionnaire, welding fumes.

I. INTRODUCTION

Welding process is one of the important processes in automotive industry. Welders in automotive industry engaged in welding works of a minimum eight hours per day and exposed towards many sorts of welding exposures. Currently, each welding workplace need to be monitored and

evaluated to ensure the minimum level of exposure is maintained according to the standards in order to maintain a healthy and safe workplace. Welding fumes are solid particles that originate from welding consumables, the base metal and any coatings present on the base metal. In welding, the intense heat of the arc or flame vaporizes the base metal and/or electrode coating. This vaporized metal condenses into tiny particles called fumes that can be inhaled. The thermal effects can cause agglomeration of the particles into particle chains and clusters that can be deposited in the human respiratory tract [1]-[3].

II. RELATED WORKS

Current study on the effect of welding fume exposure to the welder in automotive industry had been conducted in many parts of the world including US, Taiwan and Iran [4-8]. These researchers had published proves of significant health risk of developing respiratory symptoms, decreasing pulmonary function, inflammatory responses, oxidation stress, airway irritation symptoms of workers working in automotive industry particularly when engaging with welding activities.

Despite the significant effect welding fumes to welders, the measurement of the welding emission is still within the allowable range of Occupational Safety and Health Association (OSHA) and American Conference and Governmental Industrial Hygienist (ACGIH) guidelines in the investigated automotive plant [6, 9].

Table I shows the selected number of occupational disease by causal agent and invalidity pension cases reported to Malaysian Social Security Organization (SOCISO) for the year 2007, 2008 and 2009 [10-12].

TABLE I: SELECTED OCCUPATIONAL DISEASE BY CAUSAL AGENT AND INVALIDITY PENSION CASES REPORTED BY SOCISO FOR THE YEAR 2007, 2008 AND 2009 [10-12].

Occupational disease by causal agent	2007	2008	2009
Diseases due to copper or its compounds	0	3	2
Diseases due to tin or its compounds	0	1	1
Diseases due to zinc or its compounds	1	0	2
Diseases due to irritants	0	2	5
Diseases caused by manganese/toxic compounds	0	1	1
Bronchopulmonary diseases caused by hard metal	1	3	2
Occupational asthma caused by sensitizing agents or irritant inherent to the work process	4	10	10
Invalidity pension cases reported	2007	2008	2009
Malig. neoplasm of respiratory, intrathoracic	22	52	46
Diseases of the upper respiratory tract	41	26	30
Other diseases of the respiratory system	189	175	126

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Although this statistic is in general and did not reflect directly to welders, the main concern would be the poor health status of workers were due to not knowing the causal agent of the disease in their working environment. Poor safety and health precaution lead to higher rates of occupational disease.

To this date, there is still very limited study that discussed the relationship between welding emissions with health risk of welder in automotive industry in Malaysia. Thus, this preliminary measurement was conducted to get basic experience and understanding on welding fumes issues in automotive assembly line. It is expected that better understanding of welding exposure in Malaysia automotive industry will be obtained in order to promote protection through legislation or health communications strategies where such data are needed.

III. METHODOLOGY

This preliminary study was conducted during a typical eight hours working shift from 8.00 a.m until 5.30 p.m with morning breaks from 10.00 to 10.20 a.m and lunch breaks from 1.00 to 2.00 p.m. The welding section consist of three assembly line; the front under, the body side and the main line. Within these three sections, one assembly line in the front under section considered as the highest risk area had been selected for this study. This is because it is located in the corner of the building far from main entrance and windows and also adjacent with the other two sections. There are five welders in this assembly line working with spot welding. All the welders were wearing protective gears such as safety boots, safety helmet, gloves, safety goggles, aprons and back supports. However none of the welders were using respirators during work. The welding workplace does not have any extractor but uses fan on each workstation by means of controlling welding fumes. Based on visual inspection, this welding workplace seems to be not highly polluted. Three main measurements conducted in this study are as follows:

A. Personal Sampling

The government accredited laboratory in Malaysia is the Industrial Hygiene Analytical Laboratory of the National Institute of Occupational Safety and Health (NIOSH), Malaysia. Currently this laboratory is capable of analyzing welding fumes sample using the atomic absorption spectrometry (AAS) equipment for scanning one metal element per sample as shown in Table II. The price per sample for one metal element analysis is range between RM 50 to RM 60. In order to enables the most efficient use of resources, a structured sampling and analysis approach should be arrange such as the preliminary analysis using SEM-EDS before conducting the actual measurement.

The filters media were analyzed by using scanning electron microscope with energy dispersive spectroscopy (SEM-EDS) to shortlist the metal elements exist in the sample. Jenkins and Eager [13] highlighted scanning electron microscope with energy dispersive spectroscopy (SEM-EDS) found to be effective techniques for evaluating the elemental composition of welding fumes after conducted a comparison

study with inductively coupled mass spectroscopy (ICPMS), X-ray fluorescence spectrometry (XRF), neutron activation analysis (NAA), X-ray induced photo electron spectrometry (XPS), X-ray diffraction (XRD) and transmission electron microscopy with energy dispersive spectroscopy (TEM EDS). Thus, it is also highlighted that the usage of SEM-EDS would be accurate only on particles size larger than half of micrometer size such as in this study.

TABLE II: LIST OF ANALYTICAL METHOD AVAILABLE FOR ANALYSIS

No.	Chemical name	Analytical method	Analytical Technique
1	Arsenic	NMAM 7900 [14]	AAS
2	Cadmium	NMAM 7048 [15]	AAS
3	Chromium (total)	NMAM 7024 [16, 17]	AAS
4	Copper	NMAM 7300 [18]	AAS
5	Ferum	OSHA-ID 121 [19]	AAS
6	Lead	NMAM 7105 [20]	AAS
7	Manganese	OSHA ID -121 [19]	AAS
8	Nickel / Zinc / Cobalt / Aluminum	NMAM 7300 [18]	AAS

In favor of sampling method, one personal sampling pumps (Gillian 5000) were attached with 3 piece sampling cassette (SKC SureSeal) equipped with 37mm 0.8 μm mixed cellulose ester filter and supporting media according to suggested filters for welding fumes by NIOSH [21]. Each sampling pump was calibrated before and after each sampling using pump calibrator (TSI 4100 series).

The sampling pumps were set to 3 L/min flow rate. One welder was chosen to wear the sampling pump based on their location in the assembly line (middle of the assembly line). The sampling cassette was attached to the neck collar in the breathing zone of the welders. The sampling was done from 8.00a.m to 1.00 p.m to make sure the filter was not overloaded.

The filter was coated at 20mA for 60 second with Platinum and mounted on the stubs SEM-EDS which were an adapted method from Antonini et. al [22]. The filter was divided into 4 equal sections and on each section, a middle point was selected plus one more point approximately in the middle of the filters were selected for analyze. Total of 5 points were analyzed by the SEM-EDS to shortlisted the metal elements that exists in the samples.

B. Area Sampling

Area sampling for toxic gases, temperature and particulate matters 2.5 μm or less in diameter size (P.M_{2.5}) were done by using a direct reading instrument (Graywolf Toxic Gas Monitor TG 501, Graywolf Indoor Air Quality Meter IQ-410, TSI-Dustrak,). The instruments were located at the middle of the selected assembly line approximately 150 cm from the floor [23]. The measurements were done directly from 8.00 a.m to 5.30 p.m with interval time were set to 1 minutes.

C. Questionnaire's Pilot Test

Set of questionnaire were drafted to seek information from

welders in term of;

- 1) Welders basic knowledge of welding workplace hazard
- 2) Welders basic knowledge on health risk of welding fumes
- 3) Welders desire to know their health risk in the current workplace
- 4) Persistent symptom experience by the welders for the past 3 months

The questionnaires pertaining to persistent symptoms were developed by first listing out the health symptoms from Material Safety Data Sheet (MSDS) from NIOSH Pocket Guide to Chemical Hazards [24] according to metal elements that can be analyzed by NIOSH certified laboratory as outline in Table 1. These listed health symptoms were then crossed reference to American Thoracic Society and The Division of Lung Diseases(ATS-DLD-78)[25], The International Union against Tuberculosis and Lung Disease (IUATLD) Bronchial Symptoms Questionnaire [26], Quick Environmental Exposure and Sensitivity Inventory (QEESI) [27], NIOSH Indoor Air Quality Questionnaire [28] and Indoor Climate Questionnaire-MM040 EA [29]. Finally only 19 health symptoms were shortlisted for this questionnaire.

The questionnaires on persistent symptoms were then translate to Malay language by fluent speaker and try out with 2 to 4 native speakers. The questionnaires were translated back to its original language using certified translator. In favor of pilot test purpose, these questionnaires were distributed to all the welders during the beginning of the work and were collected at the end of the work shift.

IV. RESULTS AND DISCUSSIONS

A. Personal Sampling

Results of the SEM-EDS analysis of selected five points in the filters are as shown in Table III. From the 11 element tested, cobalt and nickel have significant value of mass (%) for all point tested. Thus, an actual measurement should consider for these two elements.

TABLE III: METAL ELEMENT ANALYSIS USING SEM-EDS

Metal Elements	Mass (%)					Avg.
	Point 1	Point 2	Point 3	Point 4	Point 5	
Aluminium	0.12	0.02	0	0	0.01	0.03
Chromium	1.71	2.17	1.79	3.00	2.25	2.18
Manganese	0.08	0.27	0.01	0	0.02	0.08
Ferum	0.20	0	0	0.46	0.39	0.21
Cobalt	39.72	39.5	39.81	39.23	39.07	39.46
Nickel	43.87	43.35	43.82	41.86	42.38	43.05
Copper	6.21	6.48	6.36	6.07	6.37	6.30
Zinc	6.66	7.35	6.99	6.46	7.39	6.97
Arsenic	0	0	0	0.63	0.29	0.18
Cadmium	0	0.12	0.2	0	0	0.06
Lead	1.44	0.73	1.01	2.29	1.84	1.46

Short listing of elements need to be done because each metal elements required different method of sampling and analysis. Particularly the minimum/maximum volume and

flow rate which directly will also influence the sampling time.

B. Area Sampling

Data for toxic gases (ammonia, sulfur dioxide, nitric oxide, nitrogen dioxide, carbon monoxide, carbon dioxide), PM_{2.5} and temperature were taken continuously for the whole work shift as shown in Table IV. There are no traces of sulfur dioxide, nitric oxide and nitrogen dioxide found during the whole work shift. Temperatures were slightly higher during lunch breaks due to the fans were stopped during that time resulting a high concentration of carbon dioxide although the assembly line were empty during lunch breaks. Traces of ammonia and P.M_{2.5} were low and well below the prevailing standards. This also confirm that the personal sampling of fumes will not be affect by others source of contaminants.

TABLE IV: DATA FOR TOXIC GASES, PM_{2.5} AND TEMPERATURE

Morning session (8.00 a.m to 1.00 p.m)			
parameter	min	average	max
temp	27.2	29.1	31
P.M _{2.5}	0	0.1	0.2
ammonia	0.6	1.2	2.3
sulfur dioxide	0	0	0
nitric oxide	0	0	0
nitrogen dioxide	0	0	0
carbon monoxide	0	0.1	0.4
carbon dioxide	491.0	521.2	622.0
Lunch hour (1.00 p.m to 2.00 p.m)			
parameter	min	average	max
temp	31.4	31.9	32.4
P.M _{2.5}	0	0	0.1
ammonia	0.6	0.7	0.8
sulfur dioxide	0	0	0
nitric oxide	0	0	0
nitrogen dioxide	0	0	0
carbon monoxide	0	0	0
carbon dioxide	491.0	500.2	543.0
Afternoon session (2.00 p.m to 5.30 p.m)			
parameter	min	average	max
temp	30.2	31	31.6
P.M _{2.5}	0	0.1	0.2
ammonia	0.7	1.0	1.3
sulfur dioxide	0	0	0
nitric oxide	0	0	0
nitrogen dioxide	0	0	0
carbon monoxide	0	0	0
carbon dioxide	482.0	493.7	576.0

C. Questionnaire

20 sets of questionnaires were distributed to all the welders before the work shift start and they were told to answer and returned the questionnaire before the end of the work shift. Only 11 out of 20 sets of questionnaire were returned back.

Welders were asked to choose within a 5 point Likert scale for each question as shown in Table V.

TABLE V: QUESTIONNAIRE SCORE AND CRITERIA

Score	Criteria	
5	very familiar	really want to know
4	familiar	want to know
3	not sure	not sure
2	unfamiliar	do not want to know
1	very unfamiliar	really do not want to know

According to the mean score calculated, the mean criteria were interpreted as shown in Table VI.

TABLE VI: QUESTIONNAIRE MEAN CRITERIA

Mean Score		Mean Criteria	
Min	Max		
4.21	5	very familiar	really want to know
3.41	4.2	familiar	want to know
2.61	3.4	not sure	not sure
1.81	2.6	unfamiliar	do not want to know
1	1.8	very unfamiliar	really do not want to know

In the first question, welders were asked on their basic knowledge of welding hazard. 80% to 90% of the welders were familiar with particulate matters/dust hazard and noise hazard. The lowest, only 18.2% of the workers were aware of the metal fumes hazard cause by welding operation. Overall, the welders were not sure on the hazard of toxic gases, metal fumes and radiation/heat but familiar with particulate matters/ dust and noise hazard as shown in Table VII.

TABLE VII: QUESTIONNAIRE ANALYSIS ON TYPE OF WELDING HAZARD

Type of welding hazard	Very familiar and familiar	Not sure	Unfamiliar and very unfamiliar	Mean score	Mean Criteria
	%	%	%		
Toxic gas	27.3	27.3	45.5	2.73	Not sure
Metal Fumes	18.2	45.5	36.4	2.73	Not sure
Radiation/Heat	27.3	27.3	45.5	2.82	Not sure
Particulates Matters/Dust	90.9	9.1	0.0	4.09	Familiar
Noise	81.8	18.2	0.0	4.00	Familiar

Table VIII shows the analysis of the second question to get information on welders' basic knowledge of health risk cause by welding fumes exposure. Overall, the welders were familiar of the listed health risk except for systemic toxins, neurotoxins, reproductive toxins and carcinogen.

When asked the third question on the welders desire to know the health risk exists in their current workplace, all of them agreed to 'want to know' as shown in Table 9. However, there was a high percentage of the welders who select 'not sure' mainly because they were not familiar of the listed health risk rather than 'not sure' to want to know or do not want to know the health risk exist in their current workplace. It is suggested that 'not sure' should be dropped from the answer list in the actual questionnaire to get accurate data portraying the welders' desire.

TABLE VIII: QUESTIONNAIRE ANALYSIS ON HEALTH RISK

Health risk cause by welding fumes exposure	Very familiar and familiar	Not sure	Unfamiliar and very unfamiliar	Mean score	Mean Criteria
	%	%	%		
Irritants	63.6	36.4	0	3.73	Familiar
Sensitizer	81.8	18.2	0	3.82	Familiar
Respiratory	81.8	18.2	0	3.91	Familiar
Systemic Toxins	18.2	63.6	18.2	3.00	Not sure
Neurotoxins	18.2	54.5	27.3	2.91	Not sure
Reproductive Toxins	27.3	45.5	27.3	3.00	Not sure
Carcinogen	9.1	72.7	18.2	2.91	Not sure
Mixture Effects	63.6	27.3	9.1	3.55	Familiar

TABLE IX: QUESTIONNAIRE ANALYSIS ON WELDERS DESIRE TO KNOW THE HEALTH RISK EXISTS IN THE CURRENT WORKPLACE

Desire to know the health risk exist in the current workplace	Really want to know and want to know	Not sure	Do not want to know and really do not want to know	Mean score	Mean Criteria
	%	%	%		
Irritants	81.8	18.2	0.0	4.00	Want to know
Sensitizer	81.8	18.2	0.0	3.91	Want to know
Respiratory	90.9	9.1	0.0	4.09	Want to know
Systemic Toxins	54.5	36.4	9.1	3.64	Want to know
Neurotoxins	54.5	45.5	0.0	3.64	Want to know
Reproductive Toxins	63.6	36.4	0.0	3.73	Want to know
Carcinogen	54.5	45.5	0.0	3.64	Want to know
Mixture Effects	72.7	27.3	0.0	3.91	Want to know

In the questionnaire on persistent symptoms, the welders were asked to answer how frequent each of the health symptoms is experience for the past 3 months. Persistent symptom were define as health symptoms questions answered by the welders by 'yes, every time after doing welding works', 'yes, sometimes (every week)' and 'yes, occasionally'. From the analysis, 8 symptoms were analyzed as being experience by at least 50% of the welders. The symptoms are fatigue or unusual tiredness, stuffy or runny nose, headache, difficulties concentrating or remembering things, burning or irritation of the eyes, sore or dry throat, problem with body balance and coordination and problem with numbness and tingling on part of body. Also, at least 50% of the welders agreed that 15 health symptoms out of 19 health symptoms were caused by their working environment as shown in Fig. 1.

The main concern of this persistent symptoms questionnaire is on the verification method of the questionnaire results weather it's represent the underlying true health symptoms experience by the welder. There are difficulties in acquiring the medical record of the welders since no complete medical records were available and kept with the companies. Sick leave and absenteeism from work cannot be use as a verification reference as the information

could be misleading. In order to verify the health symptom experience by the welders, spirometry test for lung function analysis were suggested for verification purpose when conducting the actual measurement on the next stage.

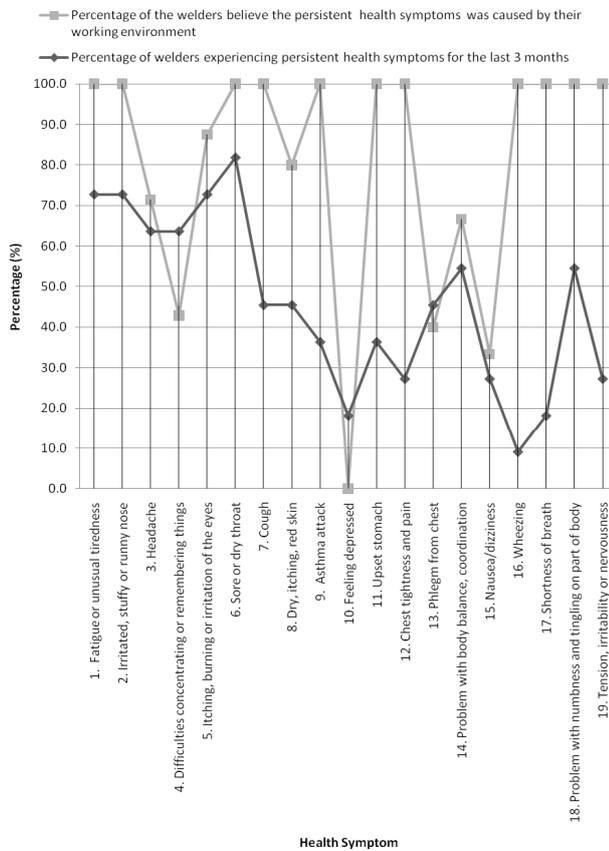


Fig.1. Health symptom analysis

V. CONCLUSIONS

Preliminary study had successfully identified valuable suggestion and alteration that need to be considered during the actual measurement in the next stage of work. Limitation on type of analytical method for analyzing metal fumes by certified NIOSH laboratory brought us to the preliminary analysis of welding fumes samples by using SEM-EDS. SEM-EDS were used to identify and shortlist the main metal element contain in the filter. This is crucial since different metal elements have different standard sampling methods which require different flow rate, different minimum/maximum volume and different sampling time. SEM-EDS preliminary analysis enables the most efficient use of resources since a sample cost around RM 50-RM60 to be analyzed by NIOSH analytical laboratory.

Toxic gases and PM_{2.5} measurement results although did not show significant finding in this preliminary measurement, the data shows that there were no other source of contaminant in the workplace that could affect the personal sampling of the welding fumes.

In the questionnaire, questions on the welders desire to ‘want to know’ or ‘do not want to know’ the health risk that exists in their current workplace should not include the ‘not sure’ answer. This could give the wrong impression about the welders opinion especially if the welders are not familiar with the health risk stated in the questionnaire.

The results of the persistent symptoms questionnaires were difficult to be verified since the company does not kept complete medical record of all the welders. Sick leaves information from panel clinic could be misleading and difficult to acquire due to confidentiality between the clinics and workers. Thus, spirometry test for lung function analysis to detect lung impairment should be carried out during the actual measurement stage as means of verification method of the persistent symptoms questionnaires.

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