Analysis of the Fume Generation Rates in the Flux Cored Arc Welding

H. B. Chae, J. H. Kim and S. C. Yang

Abstract

The characteristics of the fume generation in a flux cored arc welding were investigated using the fume collection chamber developed. The Korean Standard concerning the method for the evaluation of the fume generation rate(FGR) was updated by the evaluation method obtained through this study. It was found that the effect of humidity in the test environment should be considered and the automatic welding method had to be employed for the purpose of the exact evaluation of the fume generation rate. The results showed that the fume generation rate was influenced by the welding parameters. The important factors were the welding current, arc voltage, travel speed, and contact tip to work distance(CTWD) that affected the heat input as well as the torch angle and the shielding gas flow rate that influenced the shielding effect. The fume generation rate increased as the heat input increased and the shielding effect decreased. It was also observed that the effect of the welding current is much greater than the other welding parameters.

Key Words : Fume, Arc welding, Flux cored arc welding, Fume generation rate

1. Introduction

The arc welding fume consists of many kinds of compounds and it gives the different effects on the human body according to its composition[1-3].

The use of the flux cored arc welding(FCAW) process has grown dramatically since it had been developed due to its remarkable characteristics. The feature that distinguishes the FCAW process from the other arc welding processes is an enclosure of the flux ingredients within the continuously fed tubular electrode.

The beneficial characteristics of FCAW process are the increased productivity due to continuous wire feeding, the good weld properties due to the metallurgical effects derived from the reactions with the flux, and the shapes of weld bead formed by slag[4,5].

However, FCAW process causes the problem in working environment because it generates much more fume than other welding processes.

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Recently, the welding fume has become a hot issue in the fields of safety and industrial hygiene after some welders were diagnosed as the manganese toxicosis and nasal septum perforation[6].

This situation makes the legal regulation stronger and the employers and welders concern about the welding fume further seriously[7,8].

The basic study on the formation characteristics of welding fume is significant in developing the low fume welding wire and process, along with making the work environment clean.

The exact evaluation of welding fume generated is very important to prevent not only the heavy expenditure to construct the ventilation system from the overestimation of fume generation rate, but also the harm of welders from its underestimation.

In order to investigate the formation characteristics of the welding fume and build up the basic data to develop the low fume welding electrodes and processes, the work performed in this study examined the effect of the welding conditions such as the welding current, arc voltage, travel speed, CTWD, torch angle, and shielding gas flow rate on the fume generation rate.

2. Experiments

2.1 Construction of fume collection chamber

The fume collection chamber is generally called as 'fume box'[9]. The fume box constructed in this study is provided with two holes. One is for automatic welding process, and the other is for manual and semiautomatic. The amount of fume collected is easily affected by not only welding conditions, but also other parameters such as welding time and collecting time. That is to say, fume chamber needs to control the welding parameters, and to maintain the specified values functionally and indispensably. The design feature is shown in Fig. 1. A sight window with shaded glass is located in the center of the chamber to observe the tests. Total 12 holes (3 holes at each side) of 40mm in diameter at the lower part of chamber are provided to draw the air during testing and purging. The air sampler with the filter assembly for collecting the fume is mounted at the top of the chamber. The filter assembly should be accessible for the quick and easy change of filter and avoid fume loss by the air leakage. Fig. 2 illustrates the inner view of the fume chamber consisting of a torch mount and a turntable. The torch mount can be adjusted for the specified degree of torch angle and CTWD. The rotating speed of turntable can be set to achieve the welding speed desired. A pressure drop gage is provided to measure the pressure drop across the filter and it shows the working condition of the filter.

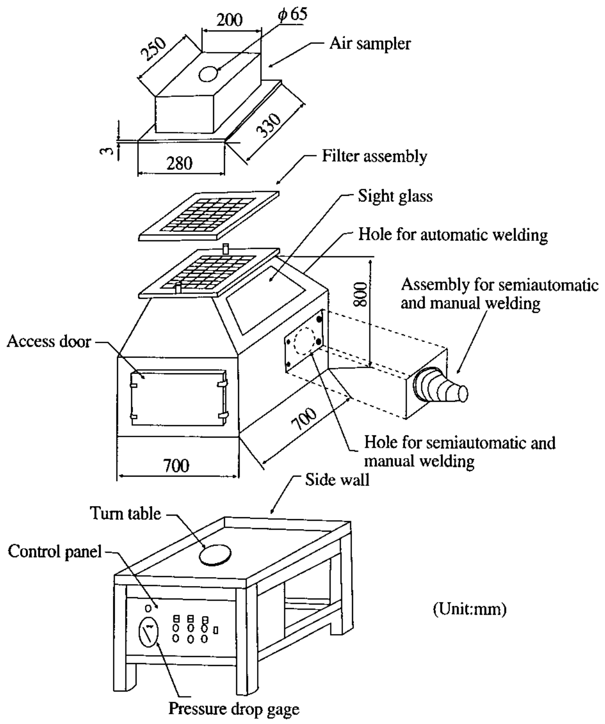

Fig. 1 Schematic drawing of the fume collection chamber constructed which has the capability of the exact control of welding conditions and can be worked with manual, semiautomatic and automatic welding processes

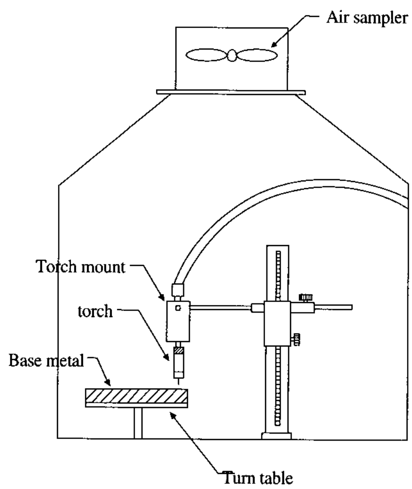

Fig. 2 Schematic drawing of internal view of the fume collection chamber

2.2 Materials, equipment and welding conditions

FGRs were measured by making bead-on-plate welds using the 600A SCR controlled type power source and 500A torch cooled by air. All test welds were made on SS 400 mild steel plates that were 21 mm thick. The thickness of plate was decided to prevent the error in the evaluation of FGR due to the deformation of base plate

Table 1 Welding conditions employed in this study

Welding Valuables	Range	Standard Condition
Current(A)	180 ~ 330	280
Voltage(V)	25 ~ 40	30
Flow rate(ℓ/min)	10 ~ 30	20
Travel speed(mm/s)	3 ~ 12	6
Torch angle(deg)	90 ~ 45	90
CTWD(mm)	17 ~ 28	20

during welding. The surface of each plate was sandblasted to remove scale before welding. AWS E71T-1 flux cored welding wire, which is 1.2 mm in diameter, was used in this experiment. Welds were made with 100% CO_2 shielding gas. Welding was performed for 30 seconds and the fume was collected for 5 minutes. The welding conditions are shown in Table 1. The composition of fume was measured by inductively coupled plasma (ICP) spectroscopic method.

2.3 Sampling and evaluation procedure

The particulate fume trapped in the filter is very hydroscopic. The filter must be dried in an oven heated between 93°C and 107°C for a minimum of one hour and then weighed immediately[10]. Fig. 3 shows the degree of how much the fume is affected by humidity in atmosphere. Under 50% of humidity, the weight change of collected fume is trivial, but it is remarkable above 85% due to the moisture pick-up from atmosphere. The weight change is about more than 10% of total fume, so that the humidity of test environment can induce the errors in test results.

The sampling and analysis of fume were conducted according to the KSD 0062[11] which was revised during this investigation. Fume generation rate was calculated by using Equation 1 that is generally used to investigate the formation characteristics of fume[12].

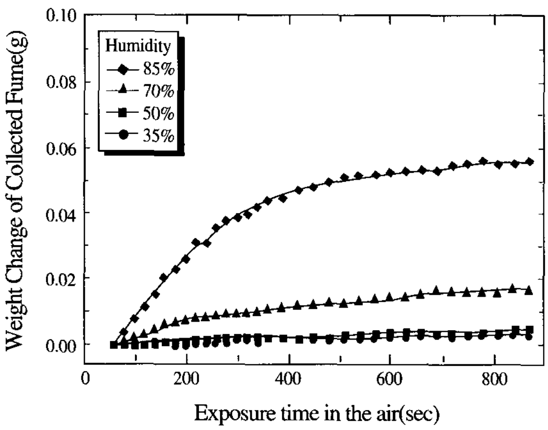

Fig. 3 The effect of humidity in measuring environment on the weight of fume collected

$$FGR = W_f - W_i \,/\, t \qquad (1)$$

FGR : fume generation rate, g/min

W_f : weight of filter after fume collection, g

W_i : weight of filter before fume collection, g

t : test time, min

The calibration should be performed before evaluation. The reproducibility and accuracy of results are the major concern of the calibration procedure that is used to confirm the setup of equipment and the test procedure. The specified values in Table 2 must be obtained using this procedure. The calibration test employs an AWS ER70S-6 welding wire and KS SS 400 mild steel base metal. Table 3 shows the welding conditions for the calibration procedure.

Table 2 The standard fume generation rate values under calibration condition

Total fume generation rate	
(g/min)	(mg/gelectrode)
0.395±5%	5.16±5%

Table 3 The standard welding condition and materials used for the calibration of fume collection chamber and evaluation procedure

Calibration condition		
Welding parameters	CTWD(mm)	20
	Torch angle (deg)	90
	Wire feed speed(m/min)	9
	Current(A)	270
	Voltage(V)	30
	Travel speed(mm/s)	6
	Test time elapsed(sec)	60
Electrode	Type	ER70S-6
	Dia(mm)	1.2
Test plate	Type	SS400
	Dimension(mm)	260×260×21
Type and polarity of current	DCEP	
Initial pressure drop(mmH_2O)	200	
Shielding gas	Composition	CO_2
	Flow rate(ℓ/min) / Nozzle dia.(mm)	20/19

3. Results and discussion

The high temperature metal vapors are blown out from the arc column. These vapors meet cold air outside the arc column, and then are oxidized and condensed immediately into solid particles. The sources of vapors can be the melted electrode tip, the detached droplet moving through the arc column, and the weld pool on the base metal[13,14]. Therefore, the composition of fume is decided by the compositions of welding wire and base metal. The composition of fume generated during welding with AWS E71T-1 is listed in Table 4.

The arc temperature increases as the welding current increases. Then the increase in arc temperature increases the amount of metal vaporization. Therefore, the FGR increases with the increase in welding current as shown in Fig. 4. If the heat input is considered as a function of welding variables(Equation 2), welding current is the most important factor on FGR because it changes in the highest order among welding variables involved.

Table 4 The typical composition of fume generated during welding with E71T-1 flux cored wire on the mild steel

Element	Na	Mg	Zr	K	Ti	Mn	Fe	Ni	Cu	Cr	Ca	Zn	Al
Content (wt.%)	0.017	8.40	0.17	0.096	0.31	4.99	23.05	0.30	0.093	0.47	14.0	0.078	23.90

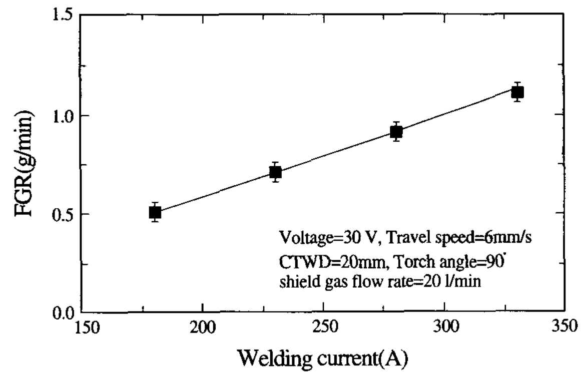

Fig. 4 The effect of welding current on the fume generation rate

$$HI = \eta \frac{VI}{S} \qquad (2)$$

HI : heat input, J/mm

η : arc efficiency

V : arc voltage, V

I : welding current, A

S : travel speed, mm/s

When all the other variables are held constant, welding current varies with the wire feed speed or the melting rate of welding wire as shown in Equation 3[15].

$$MR = WFS = aI + bLI^2 \qquad (3)$$

Of where,

MR = melting rate of electrode, kg_f/h

WFS = wire feed speed, m/min

a = constant of proportionality for anode or cathode heating. Its magnitude is dependent upon polarity, composition, and other factors, $kg_f/h \cdot A$

b = constant of proportionality for electrical resistance heating, $kg_f/h \cdot A^2 \cdot mm$

L = electrode extension or stick-out, mm

I = welding current, A

Therefore, it is reasonable and imaginable that more fume is generated at higher welding current.

Fig. 5 shows the change in FGR as a function of arc voltage. The welding conditions considered are in the range of short circuit transfer mode. Increase in the arc voltage, which is one of the terms in the equation of heat input, increases the arc temperature and the length of arc column. Therefore, the amount of vaporization is increased by increasing the arc temperature as mentioned above and by increasing the traveling time of detached droplets from the melted electrode tip through high temperature arc column. In addition, the flow of arc plasma is intensified by amplifying the arc voltage so that the oxidation is stimulated by the addition of oxygen into the arc region from the surrounding atmosphere. Therefore, the FGR increases as the arc voltage increases.

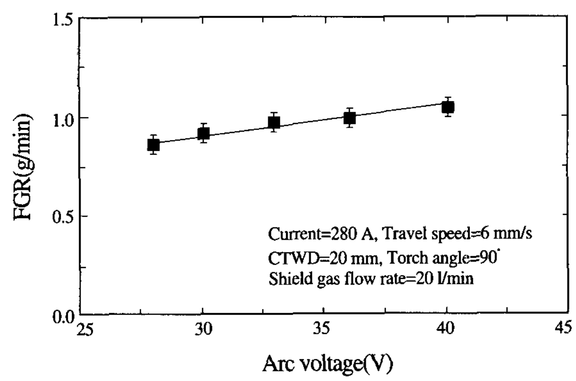

Fig. 5 The effect of arc voltage on the fume generation rate

Fig. 6 shows the effect of travel speed on FGR. The FGR decreases against the increasing travel speed because travel speed is inversely proportional to the heat input. In addition, with increasing travel speed, the moving speed of arc plasma becomes faster, so that there would not be enough time to immerse the arc into the weld pool and to evaporate the metal vapor. Thus,

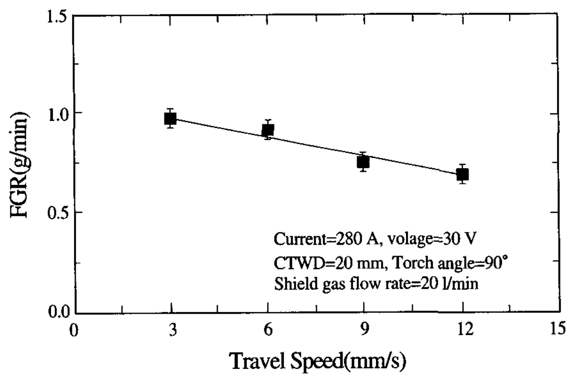

Fig. 6 The effect of travel speed on the fume generation rate

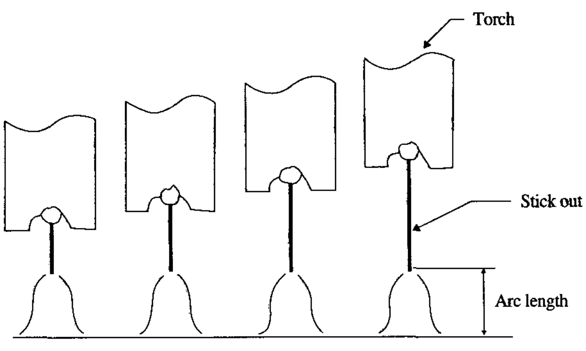

Fig. 7 The variation of electrode extension without changing the arc length

although the length of bead on the base plate is longer, the surface area of weld pool, which brings out vaporization, is smaller.

Even though CTWD is not a term involved in the heat input equation, it affects the magnitude of welding current as shown in Equation 3. Fig. 8 illustrates the schematic drawing of the stick-out that was elongated by increasing CTWD with the other variables fixed. In the normal ambient, there is minor effect on the internal resistance that is amplified by lengthening the stick-out,

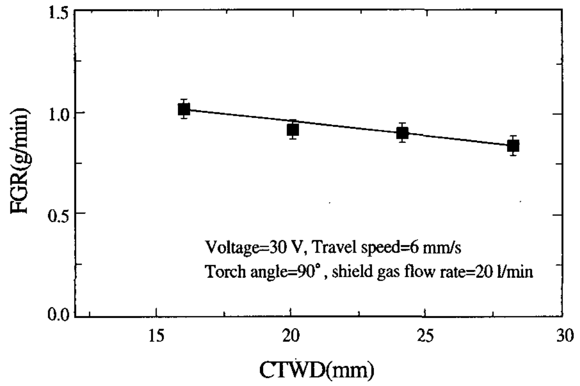

Fig. 8 The effect of contact tip to work distance on the fume generation rate

but not in high temperature around the arc. Therefore, increasing the stick-out contributes to drive the welding current downward, which, in turn, decreases the FGR as shown in Fig. 8.

Shielding effect depends upon both torch angle and flow rate of shielding gas. It is shown in Fig. 9 that the FGR increases with inclining the torch. The FGR increases as the torch angle decreases from the 90 degree due to the decrease in arc stability and the increase in spatter generation. In addition, the shielding effect is reduced as the inclined angle increases due to the difference between the flowing direction of shielding gas and the falling direction of droplets.

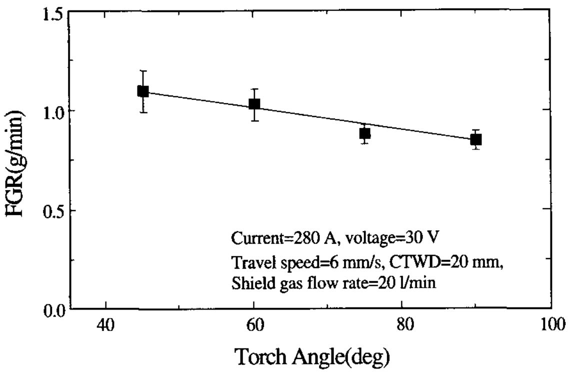

Fig. 9 The effect of torch angle on the fume generation rate

Fig. 10 shows the effect of the shielding gas flow rate. This experiment was conducted with CO_2 shielding which provides the oxidizing agent in arc area and causes the oxidation of vapors in some portion before exposure to the atmosphere. Therefore, it does not show big change in the FGR as a function of shielding gas flow rate. The flow rate of shielding gas must be high enough to protect the welding zone against the oxygen from the

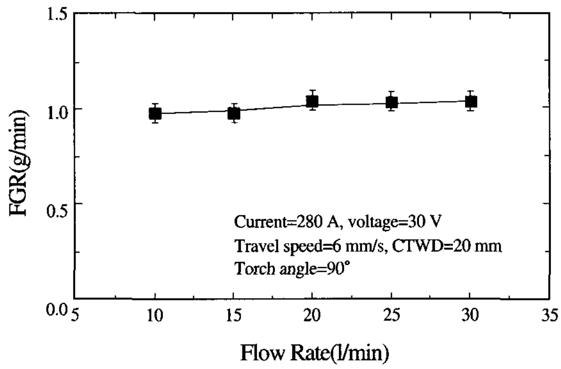

Fig. 10 The effect of shielding gas flow rate on the fume generation rate with CO_2 shielding

atmosphere. If not, the oxidation is intensified because the shielding effect is decreased by accelerating oxygen pick-up. However, excessive flow rate is not effective in reducing FGR due to the intensified turbulence. Therefore, it must be optimized.

Fig. 11 shows the relationship between the FGR and the heat input that is calculated for each welding condition employed in this study. The FGR increases the heat input increases as expected.

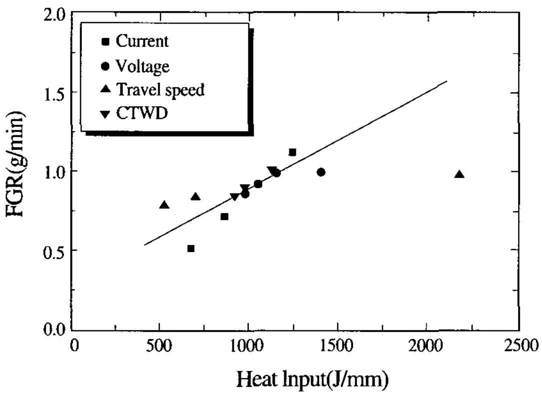

Fig. 11 The correlation between fume generation rate and heat input calculated from the welding conditions employed in this research

The factors, which decides the portion of each element in the welding fume collected from the specific welding materials, are the contents of element in the sources and the heat of vaporization(Δ Hv) of the element as shown in Table 5. It is expected that FGR of each element is linearly proportional to the content of element in the sources and inversely proportional to the heat of vaporization of each element.

Table 5 Heat of vaporization of common elements in welding fume

Element	Δ Hv (KJ/mol)	Element	Δ Hv (KJ/mol)	Element	Δ Hv (KJ/mol)	Element	Δ Hv (KJ/mol)
F	3.27	Ca	153.60	Cu	300.30	Ag	250.58
Na	96.96	Ti	421.00	Zn	115.30	Cd	99.57
Mg	127.40	Cr	344.30	As	34.76	Sn	295.80
Al	293.40	Mn	226.00	Zr	58.20	Sb	77.14
Si	384.22	Fe	349.60	Nb	682.00	W	824.00
K	79.87	Ni	370.40	Mo	598.00	Pb	177.70

The study about the elemental FGR, which shows the fume formation characteristics of each element, will be investigated in the future work.

4. Conclusion

1) The fume generation rate in flux cored arc welding was influenced by the welding parameters such as welding current, arc voltage, travel speed and CTWD. The FGR is proportional to welding current and arc voltage, and inversely proportional to travel speed and CTWD. These relationships are due to the effect of those parameters on the magnitude of heat input. The welding current was the most important factor among them.

2) The other factors were the inclined torch angle and shielding gas flow rate. The FGR increases as the inclined torch angle decreases due to arc stability, spatter generation and decrease in shielding effect. However, the FGR was not influenced by the shielding gas flow rate because 100% CO_2 shielding, which provided the oxidation medium into the arc, was used.

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