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Experimental Investigation of the Effects of Parameters on CO_2 and CO Emissions during FCAW of Structural Steel.

Estimation and Evaluation of Environmental and Health Impacts

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Welding is one of the most preferred manufacturing methods in heavy industry and there are more than 1 million welders around the world. Gas metal arc welding is one of the most utilized welding processes and as a nature of this process, especially in welding of carbon steels, deleterious gases such as carbon dioxide and carbon monoxide are emitted. Not only do these gases harm worker's health but also affect the environment adversely. Although carbon dioxide, whose global warming potential is 1, may not be seen as a significant contributor to global climate change, this emission to air should be considered when large amounts are emitted through different sources such as heavy industry, manufacturing, transportation, and residential areas. Especially in developed countries, global climate change has been a great concern and the measures taken against greenhouse gases are increasing due to cumulative environmental impacts. In this study, experimental investigation of the effects of wire feed rate and shielding gas mixtures on CO_2 and CO emissions in flux cored arc welding of low carbon steel has been realized and worldwide share of gas metal arc welding based CO_2 emissions on global warming was estimated. In addition, health effects of CO_2 and CO emissions were evaluated by comparing the recordings with NIOSH TWA and ceiling REL values.

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1. Introduction

Gas metal arc welding (GMAW) is an electric arc welding method, where the arc is struck between the constantly fed wire electrode and the work piece and shielding gas is supplied externally to protect molten metal from surrounding atmosphere [1]. Flux cored arc welding (FCAW) is a semi-automated or fully automated gas metal arc welding method, which uses a tubular cored wire instead of solid wire (Fig. 1b). The flux cored wire comprises of outer metal sheath and the inner core, which is filled with mineral flux, iron powder and slag formers (Fig. 1a). The current density is higher with cored wires because current flows through the outer shell (sheath) of the wire; whereas current is carried through the total cross-section of the solid wire [2]. Figure 1 shows the flux cored wire and FCAW principle.

Rutile cored wire is preferred in welding of machinery, shipbuilding and steel constructions because it has high deposition rate and Charpy V-notch toughness. There are some researchers who have pursued research on emissions emerged from either metal cored or flux cored wires. Popović et al. researched the fume and gas emissions occurring during arc welding. The authors estimated the influence of the types of filler materials on the toxic emissions. According to the study, manganese and CO are produced in remarkable amounts from metal cored wire. Besides, phosphorus and aluminum have high concentrations in self-shielded wire [5]. In a different study, Matusiak and Rams investigated the hazardous emissions and gases generated during unalloyed, low-alloy and high-alloy steel welding by using different tubular electrode wires such as rutile flux cored wire, basic flux cored wire and metal cored wire. The emission volumes are calculated and compared with other types of arc welding processes [6]. Yoon et al. studied on total and soluble metal contents in flux-cored arc welding fumes. The authors compared both soluble and insoluble metal contents

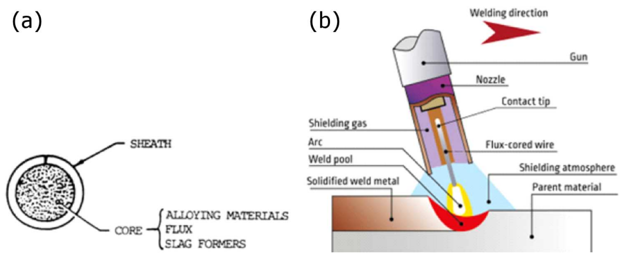

Fig. 1. Flux cored wire (a) [3], FCAW principle (b) [4].

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generated from flux-cored arc welding using non-stainless and stainless steel. The results showed that the total metal amounts occurred during non-stainless steel welding are higher than stainless steel [7]. Chung and Carter investigated the welding fume which occurred in breathing zone of workers. They took samples from breathing zone and measured the chromium contents of the welding fume and reached that the ratio of chromium is 17.7% while the manufacturer's data sheet indicates that the ratio is 11% [8]. In a recent study, the effect of different shielding gas mixtures on mechanical properties and metallurgical characters are investigated. The surface of welding area is analyzed with scanning electron microscope (SEM) [9]. Mohamat et al. studied on the effects of welding penetration, microstructural and hardness on the welding area with the variables in welding speed, current, and arc voltage [10]. Some other studies are realized on the influence of shielding gas on fume formation rate for gas metal arc welding (GMAW) of plain carbon steel [11], influence of shielding gas on fume size morphology and particle composition for GMAW [12], fume generation and control in GMAW [13], fume emissions occurring in different gas mixtures during GMAW [14].

2. Experimental study

Rutile cored wire (EN ISO 17632-A: T 42 2 P C 1 H5) with 1.2 mm diameter was utilized in this study for FCAW of round Grade A (ASTM A 131) shipbuilding steel with 290 mm diameter and 6 mm thickness. Table I shows chemical compositions of welding wire and base metal. Two different settings for wire feed rates (i.e. 4 m/min and 6 m/min) and shielding gas mixtures (i.e. 50% CO_2–50% Ar and 75% CO_2–25% Ar) were used in order to observe the effects of these parameters on CO_2 and CO emissions. Welding was pursued for 30 s with water cooled Expressweld 501W GMAW power source. Welding voltage, welding speed and shielding gas flow rate were kept constant at 32 V, 200 mm/min, 20 l/min, respectively. Shielding gases were mixed using Witt KM 60-3 gas mixer. Blower rpm of the fume chamber was also kept constant to exhaust fume and gases. In order to sample gas emissions, Mobydick 5000 multi gas analyzer was utilized. PCE-423 hot wire anemometer was used to measure the air flow speed through the duct. Gas analyzer started recording data when the arc was on and continued recording the data after the arc was off until the fume chamber was cleared. Probes of the anemometer and the gas analyzer were placed 800 mm above the base material. Speed of the air flow was measured as 0.2 m/s. Experiments were run three times for each condition and average current and voltage values were also recorded.

3. Results and discussion

3.1. Total CO_2 and CO emissions

Mass of 1 spool rutile cored wire is 15 kg and the length of the wire was calculated to be 1.7×10^6 m. Arc on times

TABLE I

Chemical composition of Grade A steel and rutile cored wire (wt%)

Material/wire electrode	C	Mn	Si	P	S
Grade A	0.14	0.67	0.22	0.011	0.012
rutile cored	0.06	1.30	0.50	0.015	0.015

for 4 m/min and 6 m/min were calculated as 425,000 and 283,333 min, respectively. Gas analyzer's sampling rate is 3 l/min and gas sampling was realized for 1.25 min. Therefore, gas analyzer's sampling volume was calculated as 3.75×10^{-3} m^3. Volumetric air flow through duct with 0.3 m diameter in 0.2 m/s air flow speed was calculated to be 0.85 m^3/min and found to be 1.06 m^3 for 1.25 min. Volumetric percentages of CO_2 and CO TWA readings were converted into ppm and concentrations in mg/m^{-3} were calculated [15]. Then, CO_2 and CO amounts were calculated according to sampling and air flow volumes for 1 min of welding.

Based on time weighted average readings for CO_2 and CO, total emissions were calculated for 1 spool (15 kg) of rutile cored wire (Table II). According to actual data of one shipyard, 963 spools of rutile cored wire has been used in building of a chemical tanker with 100 m length and 5,000 dead weight tons (dwt). Total CO_2 emission in building of this chemical tanker with these parameter settings would lead to emissions 15.3, 21.2, 10.4, 14.3 tons. Similarly CO emissions would be 482, 602, 376, and 456 kg.

3.2. Health effects

Table III presented the instantaneous maximum and TWA recordings of CO_2 and CO gases. In Fig. 2, CO_2

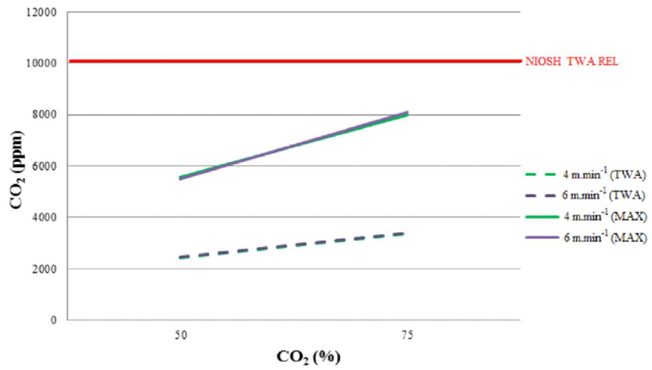

Fig. 2. CO_2 gas emission (ppm) versus wire feed rate and CO_2 percent in shielding gas mixture.

gas emission (ppm) versus wire feed rate and CO_2 percent in shielding gas mixture are shown. Figure 3 presented the CO gas emission (ppm) versus wire feed rate and CO_2 percent in shielding gas mixture. As we know, when wire feed rate was increased, average current and heat input also increased, since the voltage was constant. When wire feed rate increased from 4 m/min to 6 m/min, instantaneous maximum CO_2 readings were similar but instantaneous maximum CO readings were higher for both shielding gas mixtures. Instantaneous maximum CO_2 and CO values were higher, as expected, with the increase in CO_2 share in shielding gas mixture. This is also true for TWA for both gases. TWA values were observed to increase with the increase in wire feed rate for the same shielding gas mixtures.

TABLE II

Estimated total CO_2 and CO gas emission amounts for 1 spool and the whole chemical tanker (TWA — time weighted average)

Wire feed rate [m/min]	4		6	
gas mixture [%]	50 CO_2–50 Ar	75 CO_2–25 Ar	50 CO_2–50 Ar	75 CO_2–25 Ar
TWA CO_2[vol.%]	0.243	0.337	0.248	0.342
CO_2 amount for 1 spool [kg]	15.9	22	10.8	14.9
CO_2amount for a chemical tanker [tons]	15.3	21.2	10.4	14.3
TWA CO [vol.%]	0.012	0.015	0.014	0.017
CO amount for 1 spool [kg]	0.500	0.625	0.390	0.473
CO amount for a chemical tanker [tons]	0.482	0.602	0.376	0.456

TABLE III

Instantaneous maximum and TWA recordings of CO_2 and CO gases

Wire feed rate [m/min]	Gas mixture [%]	Max CO_2 [vol.%]	TWA CO_2 [vol.%]	Max CO [vol.%]	TWA CO [vol.%]	Avg. current [A]
4	50 CO_2–50 Ar	0.556	0.243	0.026	0.012	165
	75 CO_2–25 Ar	0.800	0.337	0.032	0.015	175
6	50 CO_2–50 Ar	0.550	0.248	0.029	0.014	225
	75 CO_2–25 Ar	0.810	0.342	0.038	0.017	235

The National Institute for Occupational Safety and Health (NIOSH) recommends 10,000 ppm as time weighted average recommended exposure limit (REL) for CO_2 and 35 ppm for CO. In addition, NIOSH's ceiling REL for is 30,000 ppm for CO_2 and 200 ppm for CO [1]. It is clearly seen that CO_2 recordings in this study did not pose any threats to human health. Unlike, CO recordings for TWA exceeded NIOSH TWA REL and instantaneous recordings exceeded NIOSH ceiling REL, which mean they pose a health risk for the welders.

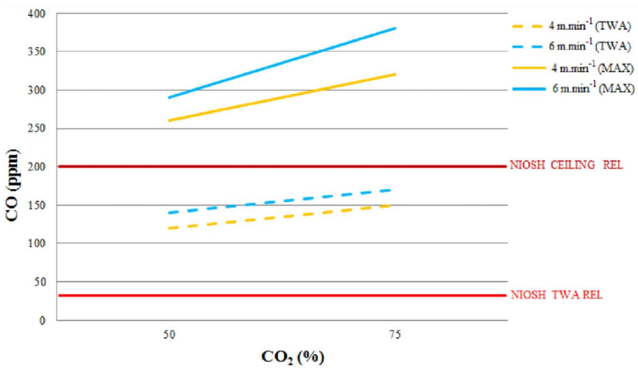

Fig. 3. CO gas emission (ppm) versus wire feed rate and CO_2 percent in shielding gas mixture.

4. Conclusion

Flux cored arc welding of low carbon steel (Grade A) was realized and the effects of wire feed rate and shielding gas mixtures on CO_2 and CO gas emissions were researched. Conclusions are summarized as follows.

* Increase in CO_2 content of the shielding gas yields to higher CO_2 emissions. There is a slight increase with higher wire feed rate setting (i.e. 6 m/min). There is a similar trend in CO emissions as well.

* Total estimated CO_2 amount in building of a chemical tanker may be as high as 21 tons for one parameter setting (i.e. 4 m/min wire feed rate and 75% CO_2–25% argon shielding gas). As there are thousands of shipyards around the world and they build ships constantly, it could be concluded and estimated that hundred thousands of tons of CO_2 emissions are released into the environment, which might easily raise the risk of global climate change.

* CO_2 emissions are below NIOSH TWA REL but CO emissions are higher than NIOSH TWA REL as well as NIOSH ceiling REL, which may pose great risk for human health.

* It is advised to work with proper parameter settings (i.e. higher wire feed rate and shielding gas mixture with low CO_2 content) to reduce CO_2 and CO emissions released into the environment and use enough ventilation and personal protective equipment to protect human health.

Acknowledgments

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