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INVESTIGATION ON THE EFFECT OF TECHNOLOGICAL PARAMETERS ON EMISSION FACTOR IN 316L STAINLESS STEEL USING GAS METAL ARC WELDING

Growing awareness for occupational safety in the welding environment needs a sustainable welding system. Welding gases releases toxic tiny particles and gases that inflict severe health consequences in the weld zone are unsolicited. Some of the other main adverse effects are lung disease, hemoptysis, pulmonary inflammation, pneumoconiosis, etc. GMAW procedure has been used for welding 316L stainless steel plates of 3 mm, 5 mm, and 6 mm. Various current configurations with gas flow rate of 5 LPM, 10 LPM and 15 LPM were also used to achieve optimum butt joint performance and to reduce the production rate of fume contributing to cost-effectiveness. In this research a cost-effective fume extraction hood was fabricated for measuring Emission factor produced during welding. Various shielding gas compositions including Pure Argon, Pure CO₂, 92% Ar+8% CO₂ and 88% Ar+12% CO₂ were used to determine the best operating parameters in the GMAW method. To satisfy the latest Permissible Exposure Limit (PEL) legislation, optimum technical parameters for efficient welding were acknowledged with the lowest emission factor. A maximum reduction of Emission factor can be achieved by using Pure Argon. The inclusion of CO₂ as a shielding gas mixture gives higher emission factor when compared to Pure Argon. Very low emission factor were witnessed in this research when compared to previous investigations. Lower emission factor of 2941.17 mg /kg of electrode, 4411.76 mg/kg of electrode and 7352.94 mg/kg of electrode were obtained for pure argon as shielding gas with 150 A welding current.

Keywords: Emission Factor. Shielding gas. Permissible Exposure Limit. Health hazards. Glass fiber filter

1. Introduction

Fusion welding is popular in all manufacturing industries around the world for decades. Specialized GMAW is primarily used for processes that involve high-speed and standard welding of various materials. While welding, the metal vaporizes and reacts with air, producing solid metal oxides when it reaches the atmosphere due to elevated temperatures. Temperature mostly in welding pool affects metal vaporization which is caused by shielding gas properties. Chemical structure, fume particle size and emission factor may be measured during welding. In this research a cost-effective fume hood has been fabricated to measure the Emission factor. This fume hood is made of easily available material. This research also suggests the optimum technological parameters to ensure low emission factor with a simple experimental setup.

In previous studies, it is observed that numerous experiments have been conducted on the impact of welding fume forming speeds. Other articles centered on the impact of pollution

factor during welding in an open atmosphere. In this study emission factor were determined in a closed environment.

Using a control banding method, exposure to nanoparticles in welding process may be assessed and controlled [1]. The control banding tool were applied to weld mild steel and stainless steel using Metal Active Gas welding to provide semi-quantitative process data in order to extract protective measures such as local ventilation systems, exhaust gas ventilation through hoods, and containment measures. The technique is very useful to test and analyze the properties of arc welding processes such that even more environmentally safe methods may be preferred against hazardous ones.

Gas metal arc welding (GMAW) studies minimize the fumes produced by this method of welding. The report reveals metallic droplet discharge followed by metal vapor [2]. This is carried out with the application of time dependent axisymmetric two-dimensional model. Following criteria to pulse a welding process: 350 A of peak current, 30 A of background current, 9 millisecond period in a ferric wire of unit mm diameter in argon

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supply to enhance shielding. Consequently, the conclusion of fume formation is dense at the fringes of the arc near the job, resulting in a fast reaction to changes in temperature period relative to the mobility of nanoparticles around. Fume formation varies from 1 to 11 mg/s with an average rate of 5 mg/s.

Investigations on the rate of emission of fumes is achieved using fume box method. Fumes arise from high-density heat energy. Fumes consist of gases that carry out the functions of shielding or atmospheric gas combination, few or more metal particulate matter to the extreme fineness of less than 10 μm [3]. Nitrogen levels are studied in many welding procedures, and the maximum exposure are from plasma arc welding, preceded by gas welding, preceded by MMA welding, followed by MAG and TIG welding.

Number based particles size of fume particles provide us with a three-modal by normal distribution in which liquid-phase and solid-phase dominate first and second stage, and the last stage is highlighted by coarse fume particles. Parameters for welding including arc resistance, wire feed intensity and thickness of electrode are investigated and sorted. The toxic aero particles fall over the range 0.005 to 20 microns. In case if rutile and carbonate-fluorite is layered over the electrode, the initial mode had a content of about 80% to 90% nucleation, nuclei germination and coagulation. The second mode consisted of about 10% to 20% of all three characters. The last and final mode consisted of 0.02% to 0.2% of the characteristics. The fume formation during welding is not dependant on only one parameter, but on many factors [4]. This research helps to improve the hygiene and sanitation throughout welding process.

Coating the nano-aluminum precursor to that same base material culminated in a visible reduction in Cr^{6+} concentration which assisted a maximum reduction in Cr^{6+} concentration of up to 34 percent of the source welding fume using Taguchi experimental design methodology. As a matter of research, the low current with precursor concentration, and the shielding gas with higher precursor concentration offered maximum reduction. Eventually, to increase nanoparticles to reduce the formation of fumes [5].

Minimization of fume in GMAW is welded onto mild steel as well as nickel, iron, and manganese. In addition, SMAW and flux-core arc welding (FCAW) were introduced. The findings derived from a broad variety of emission factors [6]. Consequently, the study result revealed that the fume evolution amount per gram electrode ingested was the maximum in shielded metal arc welding at around 13 milligram at fumes per gram of electrode. It is seen that it was the lowest in (GMAW) of about 1.5 milligram of fume per gram of electrode. In SMAW, manganese emission is known to be 0.45 milligram of fume per gram of electrode. In GMAW, it was noted that it was suppressed by a variation of 0.09 to 0.004 milligram of fumes per gram of electrode. Ferric and ferrous emissions led to a quantity of 3.7 to 0.49 milligram of fume per gram of electrode. Moreover, the sum investment was taken into account in this analysis, which showed that it was easier to identify FCAW first, then GMAW, and finally SMAW.

A research was performed on minimising welding gases through a Nano- TiO_2 coating on electrodes. Fumes volume was observed with deposit morphology and crystallite scale. In this research, they used dip-coating technique to deposit Nano- TiO_2 on bare welding metal. The bead was deposited by the coated electrodes on IS 2062 low-carbon steel plate welds and obtained using personal air sampler gases in the welder's breathing region. The studies were formulated using Taguchi. The findings show us an 80 percent reduction of fumes breathing zone concentration and a substantial reduction of fumes concentration of Ti, Mn, Ni, Si, Cr and Fe relative to commonly available uncoated equivalents. Metallographic research reveals that welds from coated electrodes exhibit fine-grained microstructure, greater penetration depth and higher toughness values [7].

Attempts were made to minimize fumes accumulation in gas metal arc welding utilizing various types of filler materials and gas protection [8]. The author dramatically decreased fumes output by welding current intensity. As a consequence, the fumes output rate will decrease with low current strength or hold it in change. Low arc temperature and arc stability decrease fumes production. Adding NO can boost nitrous oxide.

Investigation on the impact of shielding gas composition and fuming composition during GMAW were carried out [9]. The quantity of fumes produced during welding was tested for steady flow over a range of wire-feed and arc pressures. Gasses are manufactured from carbon, manganese, iron, titanium and sodium oxide. The particle size is between 0.5 to 2 μm [10].

Voltage plays a vital role in reducing the size of the fume to avoid toxic to humans. The size of the fume increases on increase in voltage for the welding dip. In proper welding conditions the fume size was 70 nm smaller than the size. In low voltage dip transfer, ultra-fine particles are produced as compared to global and spray transfer [11]. The fumes to be produced are in the spherical which facilitates in bio-absorption. The minimum particle size was found to be 5 nm, when measured by TEM for all welding voltages.

Most of the researchers discussed about fume production during the arc welding. The comparison with simulation model was recorded between the simulation result and the experimental result. The fume produced in the downstream region is produced through a droplet formed with nanometre size [12]. The average cooling rate and the average metal vapour pressure in the downstream arc region near nucleation site was recorded as 3.43 105 K/s and 169 Pa. The exhaust fumes have been inspected in TEM and found similar to simulation results.

Al_2O_3 and TiO_2 have been used as arc stabilisers by nano-coating to reduce fumes and tertiary content, reactive metal oxide are coated to minimise hexavalent chromium concentrations in welding fumes [13]. The combined behaviour of all three materials resulted in successful reduction of both fume formation rate and Cr concentration of welding fumes. Among the tertiary nano-coated electrodes tested, an effective decrease in Cr concentration in welding smoke, representing 47 percent, with a substantial reduction in the rate of fume production and other hazardous components.

Some of the observations include coagulation of primary particles in nuclei and nucleation of condensable hot vapour. As a result of these processes, there is a formation of dust known as plasma at phase transition atmospheric conditions, turns into primary matter from droplets. He found that for the electrodes used in arc welding covered with carbonate fluorate, the primary particle density is higher than uniform spatial spread. It results in greater coagulation of primary matter. Primary matter with diameter more than 10 nm turns into cluster form that is independent of temperature. And for the ultra-fine ones of size almost nearing 2 nm, the process takes place in two varieties, which initiates in linear chain formation in agglomerate form and finally ends up in agglomerate bunches. This is how the process occurs and fume is formed from plasma(dusty). However, the plasma formation is never let to happen due to Brownian motion due to lack of potential interactions. Higher temperature and less charged ones also never let the above process happen [14]. This cluster-like formation begins at a temperature around 600 K.

During gas arc welding, chemical composition and primary particle size is examined. Welding flow evolution modelling was used in this study. The various primary particle methods also have specific chemical composition, as both multi-component condensation and droplet solidification rely solely on particle size. Due to intermodal agglomeration, different particles (which are also different in size and chemical) are taken [15]. As a consequence, preferably layers of welding fume particles on the upstream face comprising second filtered particles. And if the first mode particles are collected in the fine filter and downstream of the coarse filters (makes / results) the electrical force to operate on them in the opposite direction of fumes streams.

Broad range of potential difference and wire feed rate are important criteria for fume forming rates. Two broad spectra were studied, i.e., positive direct current electrode and negative direct current electrode. DCEP welding with diameter of 1.4 mm with a supply power of 9.5 kW. The evolution of fume was fewer as the arc covered the melted weld pool. Metal cored wire welding and DCEP solid wire welding as a conclusion, arc stability persisted longer. The best results produced by DCEN metal cored wire welding was like that of DCEP solid wire welding [16]. Fume evolution rate is successfully estimated using simple formulae ($Ba = g/kWh$). The same findings cannot be brought for DCEN metal cored wire welding.

Investigation on the loss of transmission caused by Welding fume in tapered optical fibers. In this article, he tells about the real-time method of sensing welding fumes. This method is focused on the effects of nanoparticles-induced experimentation with loss of optical fibre, which shows us that losses are determined by nanoparticles' taper waist and density. The tapered fibre is produced by averaging heat radiated from hot quartz and monitoring in real time. During the welding process, the resistance of the tapered fibre is first proved and then the failure is classified using the dimensions of welding fume particles from the experiment they infer that the sensitivity to welding fumes increases with an increase in particle size; thus, the dimensions of the taper waist decrease [17].

Biotoxicity in fumes must be reduced production during welding [18]. Adding SiO_2 to the arc-welding shielding gas reduces the toxic nature of the produced fumes. SiO_2 acts as the surface coating on the fume particles and allows them to settle at the baseline (which is called agglomeration) [19]. The inhibition of fumes occurs at higher concentrations of exposure. In GMAW and GTAW, the SiO_2 addition is indeed successful. In TMS process the welding quality is yet to be certified [20].

2. Materials and methods

Quality 316L, low-carbon 316 is immune from sensitization. It is thus used widely in heavy-gage welded parts. In this research, filler wire of 1.2 mm diameter ER316 L has been used to weld SS 316 L specimens by butt joint with Gas flow rate of 5, 10 and 15 LPM, welding speed at 200 mm / min for base metal thickness of 3 mm, 5 mm and 6 mm. The schematic setup used in this research is shown in Fig. 1.

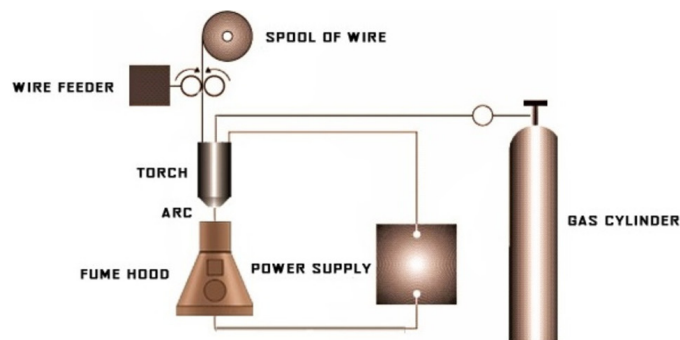


Fig. 1. Schematic setup

The experimental process parameters are 150A, 200A, and 275A of current intensities. Using Creo 5.0 software to capture welding fumes in a closed environment (Fume hood) have been modelled as shown in Fig. 2. This Fume extraction hood is fixed on the welding table to weld the specimens.

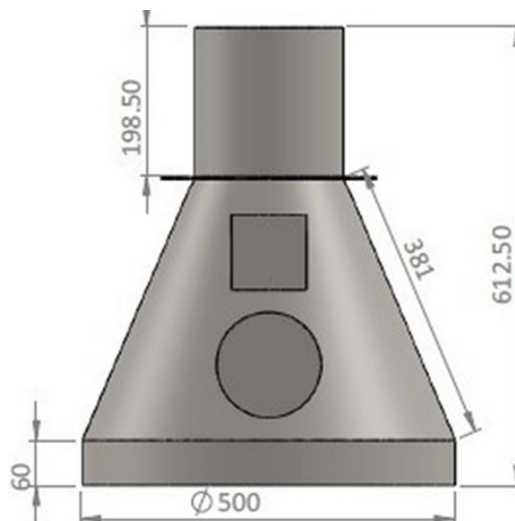


Fig. 2. Fume hood used (All dimensions are in mm.)

The chemical composition of 316 L Stainless steel is given in Table 1. and the chemical composition of ER-316 L Filler wire is given in Table 2.

TABLE 1

Chemical composition of 316 L Stainless steel

Grade	Range	C	Mn	Si	Cr	Mo	Ni
316L	Min%	—	—	—	16.0	2.0	10.0
	Max%	0.03	2.0	0.75	18.0	3.0	14.0

TABLE 2

Chemical composition of ER-316 L Filler wire

Grade	Range	C	Mn	Si	Cr	Mo	Ni	P	S	Cu
ER-316L	Min%	—	1.0	0.30	18.0	2.00	11.0	—	—	—
	Max%	0.03	2.5	0.65	20.0	3.00	14.0	0.03	0.03	0.75

During the process, some amount of welding fumes deposited on the filter paper by an extraction fan. A pre-weighted glass fibre filters (Whatman GF/A) is used to collect the emitted fumes which is then weighed to give the total weight of the fumes produced. The generated fume was collected on 240 mm diameter (Whatman GF / A) glass fibre filter, which were then re-weighted to give the total fumes produced. The weight was then used along with arc time to calculate FFR(g/min) which is equivalent to fume generation rate (FGR) or Emission factor, quoted in mg of fume per kg of filler wire (mg/kg). The ratio of the quantity of fume deposited on filter paper to the arc time determines the fume formation rate (FFR). The fume generation rate is occurred by the total mass of fumes produced per kilogram of filler electrode used. The following expression is used to calculate the Emission factor (or) FGR in mg/kg of filler electrode.

$$\text{Emission Factor} = \frac{\text{Mass of the fumes collected}}{\text{Mass of the filler wire}} \text{ in mg/kg} \quad (1)$$

Where,

M_{fume} – mass of fumes collected in filter paper, mg,

$M_{\text{filler metal}}$ – mass of filler wire used in this research, kg,

$$M_{\text{filler metal}} = V_{\text{Filler Wire}} \cdot \rho_{\text{Filler wire}} \text{ in kg} \quad (2)$$

$$\text{Volume of the wire} (V_{\text{wire}}) = 0.785 \cdot d^2 \cdot v \cdot t \cdot 10^{-3} \text{ in m}^3 \quad (3)$$

d – diameter of filler wire, (1.2 mm),

v – wire speed, (0.03 m/s),

t – time taken for welding, (60 s),

ρ – density of filler wire, kg/m³.

3. Result and discussion

The Emission factor is the measure of total fumes emitted per kilogram of filler electrode. The reduction of emission factor is critical to improve the shop floor conditions for welders, thereby decreasing sick leave due to welding fumes. In this

research Whatman GF / A filter paper is used to collect the welding fumes positioned above the welding fume hood used in this research. A sample of filter paper used to extract fumes with Pure CO₂ as a shielding gas with 15 LPM gas flow rate is shown in Fig. 3. While welding the specimens inside the fume chamber, an extraction fan is used to extract the gases produced from the welding process into the glass fibre filter paper.

Fig. 3. Filter paper with extracted fumes using CO₂

Traditionally, two-part blends manufacturers of common stainless steels are argon mixtures with either oxygen or CO₂. It is acceptable for conventional or pulsed spray transfer. Argon / CO₂ blends yield less surface oxide, good bead shape, wetting, wide penetration, and consistent quality. The compatibility of each gas with wire and base metal determines the suitability of the different combinations of gases. Emission factor for four shielding gas combinations with various gas flow rates, current intensities and different base metal thickness are given in Table 3.

As seen in Table 3 and Fig. 4, Fig. 5 and Fig. 6, the emission factor were calculated by weighing fume deposited filter paper. Three current intensities of 150A, 200A and 275 A with gas flow rates of 5 LPM, 10 LPM and 15 LPM were considered in this research. For 3 mm thick specimens, by using Pure argon as a shielding gas, lowest emission factor of 2941.17 mg/kg of electrode were obtained at 150 A current intensity for 15 LPM gas flow rate. By comparing the remaining shield gas compositions, 92% Ar+8% CO₂ gives lower emission factor than and 88% Ar+12% CO₂, and Pure CO₂. This is because the CO₂ concentration in the shielding gas increases the oxygen level which in turn leads to an increase in oxidizing ability of shielding gases and thereby increases the volume of metal oxide particles in the fumes.

Similarly for 5 mm thick specimens, lowest emission factor of 4411.76 mg/kg of electrode consumed were obtained for 150A current intensity using 15 LPM gas flow rate. And also for 6mm thick plates, lowest emission factor of 7352.94 mg/kg of electrode consumed for same 150 A current intensity using 15 LPM gas flow rate.

TABLE 3

Emission factor for 3 mm, 5 mm and 6 mm plates for various shielding gas compositions, gas flow rate and current intensity

Thickness of specimen	Shielding gas compositions	Emission Factor in mg/kg of electrode consumed for 5 LPM Gas flow rate			Emission Factor in mg/kg of electrode consumed for 10 LPM Gas flow rate			Emission Factor in mg/kg of electrode consumed for 15 LPM Gas flow rate		
		150 A	200 A	275 A	150 A	200 A	275 A	150 A	200 A	275 A
		3 mm	Pure Ar	3428.18	4005.25	3728.2	3108.66	3802.64	3526.48	2941.17
	92%Ar+8% CO ₂	4291.88	5108.19	4823.06	4189.22	4832.99	4688.66	3941.2	4726.5	4356.2
	88%Ar+12% CO ₂	6292.88	7129.35	6890.56	6056.05	6970.55	5976.52	5882.35	6792.55	5439.33
	Pure CO ₂	12863.0	14097.5	13783.6	12587.65	13978.1	12893.2	11764.7	13336.2	12549.7
5 mm	Pure Ar	4905.82	5293.05	5078.85	4686.23	5093.14	4838.65	4411.76	4931.36	4637.34
	92%Ar+8% CO ₂	6273.08	7188.29	6778.99	6006.89	6998.45	6533.55	5882.4	6792.55	6362.4
	88%Ar+12% CO ₂	9100.88	10589.6	9892.88	9007.55	10104.5	9586.97	8823.53	9853.73	9361.33
	Pure CO ₂	18111.7	19673.3	18884.2	17881.2	19078.5	18691.2	16176.4	18675.7	17455.3
6 mm	Pure Ar	7955.97	8448.09	8088.48	7589.65	8259.06	7889.15	7352.94	8052.4	7762.34
	92%Ar+8% CO ₂	9270.84	10897.5	9768.66	9078.87	10008.5	9600.78	8823.5	9873.6	9436.5
	88%Ar+12% CO ₂	12891.5	14079.1	13790.5	11893.1	13893.1	12908.1	11792.4	13582.6	12652.3
	Pure CO ₂	20777.5	22089.15	21305.45	19286.48	21863.74	20888.48	19117.64	21787.94	20365.64

Fig. 4, Fig. 5 and Fig. 6 clearly depicts the emission factor generated during welding by considering various shielding gas compositions on X – axis and Emission factor on Y – Axis. From the figure, it is clear that Pure CO₂ gives highest emission factor when compared to other shielding gas mixtures. And the emission factor is low for Pure Argon when compared to other compositions. Welding fume hood with different experimental approach were carried out by researchers so far [10]. Some of the researchers have calculated the fume formation rates (FFR) alone [9]. In this research, Emission factor were determined by using cost- effective fume hood.

Moreover, during GMAW welding steels, CO₂ and O₂ are useful at times, and even necessary. Accordingly, argon oxygen additives are typically less than 12% per volume, whereas GMAW mild steels may use 100% CO. Steel wires must contain strong deoxidizing elements when used with oxidising gases, particularly mixtures with high concentrations of CO₂ or O₂ and especially 100% of CO₂.

CO₂ content promotes large droplets, lengthy cycles of separation, elevated arc temperatures and increased fume produc-

tion. Pure argon, as a shielding gas, is strong and fume formation rate is lower in all the mixtures examined. Argon prevents the molten weld pool from developing toxic metal oxide particles using atmospheric oxygen.

As seen from the Table 3 and Fig. 4, Fig. 5 and Fig. 6, it is evident that Emission Factor increases as current intensity increases. Because at high current intensities, the metal transfer mode seems to be more of spray transfer and the number of droplets that are transported by increased unit time.

But as shown in Fig. 4, Fig. 5 and Fig. 6, the emission factor value stagnates at a certain current and the emission factor starts to decline as the current intensity increases. Emission factor increases for various thickness of base metals as shown in Fig. 4, Fig. 5 and Fig. 6.

The most significant welding considerations based on shield gas, voltage and current. A 1-5% voltage shift for fixed current is feasible with argon-based shielding gas for up to 20% Emission factor change. Emission factors vulnerability to voltage and current shifts, in contrast, is much less important for CO₂ shielding gases. Previous work demonstrates that at the same

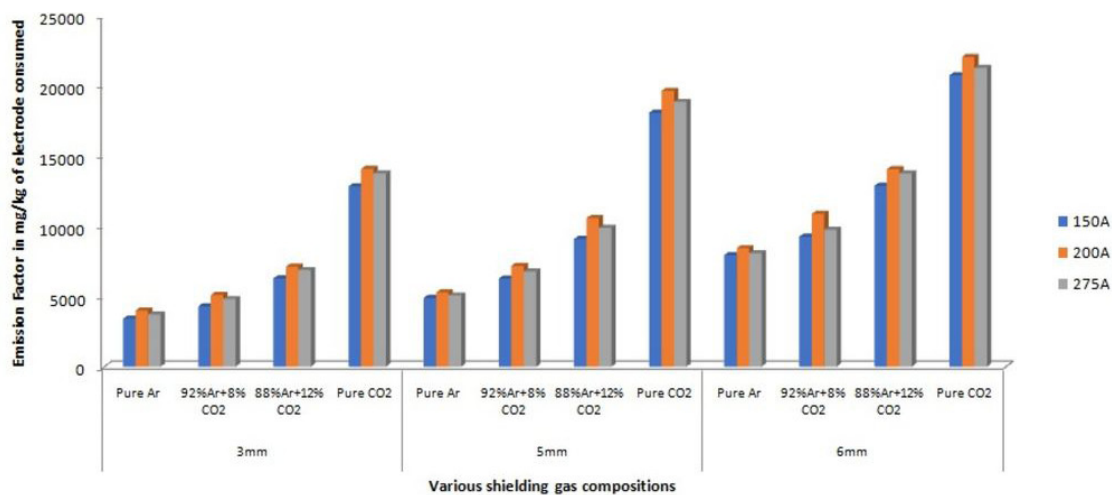


Fig. 4. Emission factor for gas flow rate of 5 LPM

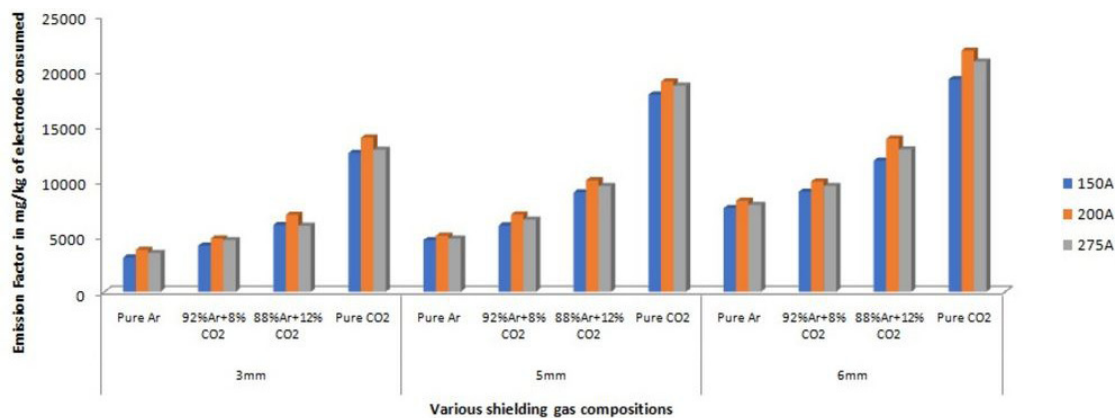


Fig. 5. Emission factor for gas flow rate of 10 LPM

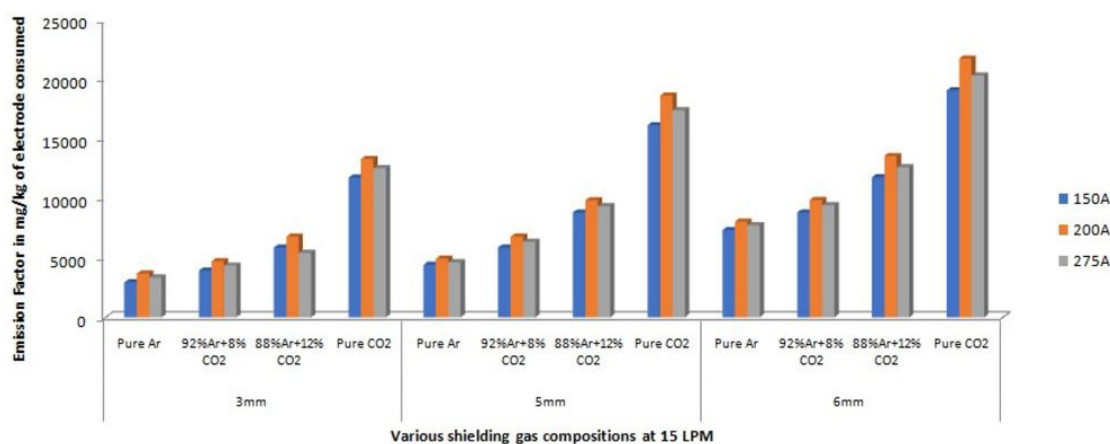


Fig. 6. Emission factor for gas flow rate of 15 LPM

current intensity, the arc length declines with the increase in CO₂ content in the mixture. The lower CO₂ mixtures result in higher “arc force”, which may penetrate deeper. With respect to test reproducibility, great care would be required while welding with argon-based shielding gases to preserve the voltage and current settings.

From the result, it is clear that large reductions in emission factor were due to reductions in the arc length and an increase in current intensity, accomplished by encouraging the ‘drop-spray’ transfer state and reducing repelled globular transfer. The aim of this research was to recognize how shielding gas composition and welding current affect Emission factor and shielding gas compositions. This study connects the impact of shielding gas on emission factor and technological parameters for analyzing welding fume hazard to workers.

4. Conclusion

A cost effective welding fume hood were fabricated to investigate the emission factor during welding within a closed environment. This experimental research suggests that technical parameters such as welding current strength, gas mixtures, and the type of electrode used have a major effect on minimizing

the emission factor. Yet this research begins a new dimension in discussion with the welding community on workplace health and safety. These experimental results portrayed minimum emission factor with 15 LPM gas flow rate when compared with 5 LPM and 10 LPM flow rates. This same finding showed that the increase in CO₂ mixtures produce maximum emission factor for all the gas flow rates. It influences emission factor and its effects on metal transfer mode and arc characteristics. For 3 mm, 5 mm and 6 mm thick specimen, Pure Argon mixture as shielding mixture results in lowest emission factor. For 3 mm thick plates, lowest emission factor is witnessed as 2941.17 mg/kg of electrode in 15 LPM flow rate for 150A welding current using Pure Argon as a shielding gas. For 5mm thick plates, minimum emission factor were obtained as 4411.76 mg /kg of electrode using pure argon as a shielding gas with 15 LPM flow rates for 150 A. Similarly for 6mm thick plates pure argon gives lower emission factor as 7352.94 mg/kg of electrode. Low emission factor during welding prevents welder’s health from hazards produced by metal fumes and gases. Emission factor increases as carbon dioxide emissions increase in argon-based shielding gases. In previous investigations, by using a fume hood setup emission factors were investigated using various shielding gas mixtures. But in this research a cost effective fume hood were fabricated and experiments were carried out to obtain

superior results when compared to previous research. The study reveals the need for a control technique to reduce welding fumes in the source and comply with new exposure limits legislation.

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