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ORIGINAL ARTICLE

Reduction of fume and gas emissions using innovative gas metal arc welding variants

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Abstract New environmental, health and safety legislation, both in the EU and in the USA, is driving the need for the study of new welding processes, and the selection of the operational procedures that will reduce fume emissions and will promote a healthier, safer and more productive work environment. Actually, there are a significant number of publications related with gas metal arc welding hazards. However, for the new gas metal arc welding hazards variants, especially cold metal transfer, there is no data available concerning fumes and gases emissions. This paper attempts to point out ways of reducing the harmful effects of gas metal arc welding processes using different filler materials, different shielding gases, different operational welding procedures and three welding processes: gas metal arc welding process and two variants, pulsed gas metal arc welding and cold metal transfer. The effect of nitrogen oxide addition to the shielding gas composition on the amount of welding fumes and gaseous emissions produced during welding is also analysed. The amount of fume and gases generated during welding was measured over a range of current intensity and arc voltages, using the standard procedures contained in EN ISO 15011-2 [1]. The data presented give a summary of the different gas metal arc welding variants and their relations to fume generation rates and gases emitted. The results obtained give indications on measures to be taken in order to reduce fume and gas emissions. In general, the minimisation of fume formation rate can be achieved by using lower energy gas metal arc welding variants, gas shielding with low CO_2 and O_2 contents and "green" wires.

Keywords Gas metal arc welding · Fume formation rate · Gas emissions · Cold metal transfer

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1 Introduction

Any material is a potential source of fume when heated. Welding is accompanied by high-temperature heating and evaporation of base and electrode metal. Welding fume is a result of condensation of the gas and vapour mixture formed when welding [2].

Welding fumes are very small particles that are formed when the vaporised metal rapidly condenses in air, and are typically too small to be seen by the naked eye, but collectively, form a visible plume. Welding fume gets into the welder's body mainly through the breathing organs. It is known that the most respirable particles are of size 0.1 to 5 μm; particles more than 5 μm in size are deposited in the upper respiratory tract and those less than 0.1 μm in size are mainly removed from the body by exhalation [2, 3]. Thus, welding fume particles are among the most respirable ones (Fig. 1).

The health effects associated with metal fumes depend on the specific metals present in the fumes, but there is a concern that these may range from short-term illnesses, such as metal fume fever (i.e. flu-like symptoms), to long-term lung damage and/or neurological disorders, such as lung cancer and/or Parkinson's disease [4–6].

Gases are also generated from welding, which may include carbon monoxide, ozone and nitrogen oxides.

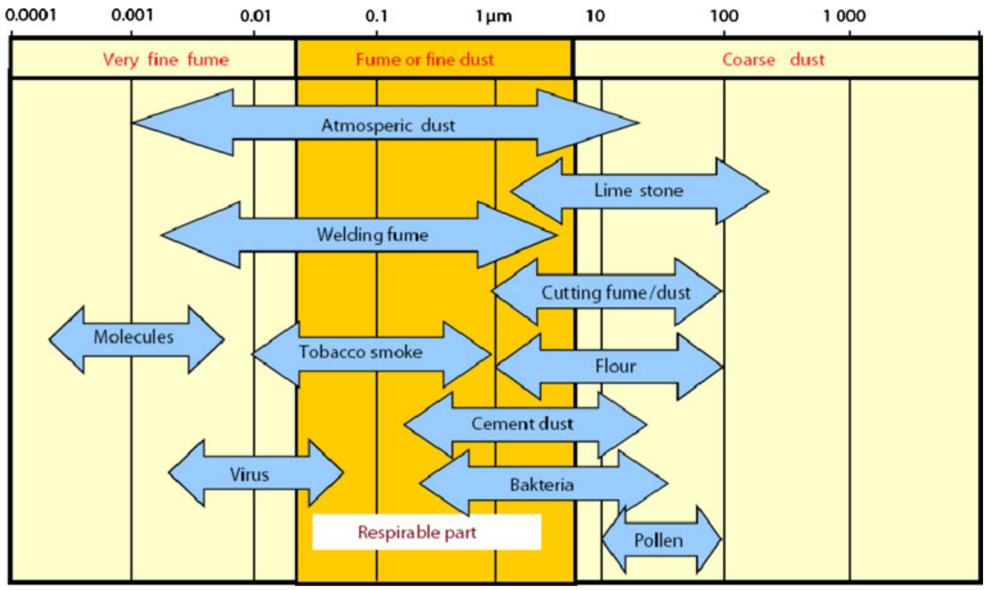


Fig. 1 Particle sizes of different fumes [3]

Carbon monoxide (CO) is an odourless, colourless gas that may be formed by the use of carbon dioxide (CO_2) as a shielding gas. Overexposure to CO inhibits the body's red blood cells to sufficiently carry oxygen to other tissues within the body, which subsequently results in asphyxiation. Welding does not normally generate CO at high enough levels to be a concern; however, high levels of carbon monoxide may potentially accumulate when welding in confined spaces. There is also a potential of an oxygen-deficient atmosphere if welding inside of a confined or enclosed space if an inert gas (such as argon) is used as the shielding gas [7].

Nitrogen dioxide and nitric oxide are produced by the interaction of ultraviolet light (from the welding arc) with the surrounding air. These compounds are irritating to the eyes, nose and throat. High exposures can also cause fluid in the lungs and other long-term pulmonary illnesses [8]. The present paper addressed welding fume emissions effect on the breathing area of the welder though its impact is also important on what concerns climatic changes, since the welding arc is an emitter of ozone, carbon dioxide and other pollutants.

1.1 Welding processes and fume generation rates

The type of welding process is directly related to the amount of fumes and gases that are generated. Therefore, it is important to have a basic understanding of the welding process in order to assess the risk of exposure.

1.1.1 Gas metal arc welding

Gas metal arc welding (GMAW) is typically used for most types of metal. This process involves the flow of an electric arc between the base metal and a continuously fed consumable electrode. Shielding gas (necessary to protect the weld bead and weld pool) is supplied externally. Due to the intense current levels, GMAW produces significant levels of fumes and nitrogen oxides.

The process is versatile, since it can be applied for all position welding; it can be easily automated and can easily be integrated into the robotized production centres. These advantageous features of this process have motivated many researchers to study the GMAW process in detail [8].

Despite its wide application, the GMAW process has some limitations regarding the control of metal transfer. Although GMAW was initially developed as a high deposition, high welding rate process facilitated by continuous wire feed and high welding currents, susceptibility to porosity and fusion defects, limited its use to applications where weld quality was not of paramount importance [8]. However, in recent years, as the industries have striven to become more efficient, there has been renewed interest to improve quality and to overcome the limitations of conventional GMA welding which led to the development of new variants. Examples are the use of pulsed current in the 1980s and more recently, the cold metal transfer (CMT) [9–11].

1.1.2 Pulsed gas metal arc welding

The pulsed GMAW (GMAW-P) process works by forming one droplet of molten metal at the end of the electrode per pulse. Then, just the right amount of current is added to push the droplet across the arc and into the puddle. Unlike conventional GMAW, where current is represented by a straight line, pulsed GMAW drops the current at times when extra power is not needed, therefore cooling off the process. It is this "cooling off" period that allows pulsed

GMAW to weld better on thin materials, control distortion and run at lower wire feed speeds [8].

1.1.3 Cold metal transfer

The recently new welding technique called CMT was introduced by Fronius in 2005. From the point of view of welding, 'cold' is a relative concept. In the CMT technique, the work pieces to be joined remain considerably 'colder' than in conventional GMAW process. The main characteristic that distinguishes the CMT welding process from the conventional GMAW is the incorporation of the wire motion into process-control. The wire is moved forward and backward—once short circuit has happened—with a frequency of up to 70 Hz. The wire retraction assists droplet detachment and thus a current-free material transfer. Due to the nearly current-free material transfer and the discontinuation of the short circuit, the heat input is substantially reduced compared to conventional metal arc welding and it is virtually spatter-free [9, 10].

In addition to the welding process, studies have shown that the fume generation rate is also influenced by the welding procedures, the chemical composition of the shielding gases, the filler and the base material, the presence of coatings and the time and severity of the exposure [11, 12].

With the outcome of new welding equipment and consumables the welding characteristics and applications were considerably improved, simultaneously the revision of exposure limits has resulted in even lower limits on the release of toxic substances during welding and this downward trend can be expected to continue in coming years, as a way to reduce the incidence of professional diseases in welders [7–13].

As a result of these new impositions, manufactures of both equipment and consumables are forced to take severe measures in order to decrease pollutant emissions.

Actually, there are a significant number of publications related with GMAW hazards [14–17]. However, for the new GMAW variants, especially CMT, there is no data available concerning fumes and gases emissions, being its evaluation of great interest.

In what concerns the influence of shielding gas mixtures on fume emissions there is also well-documented literature. However, there are shielding mixtures that give rise to some discussion/controversy, as those for which little quantities of NO (nitrogen oxide) has been added. These mixtures have been introduced in the market some years ago claimed to have environment benefits, although never rightly confirmed.

The mechanism of fume formation was already been a matter of study by the authors [15, 18], thus it will not be discussed in the present paper.

In this context, the present paper describes a comparative study between the fume and gases emissions resultant of GMAW process and of two of its variants (GMAW-P and CMT). It also studied the influence of NO addition to the shielding gas mixture on the fume formation rate and gas concentration.

2 Materials and methods

Three arc welding processes were tested, GMAW, GMAW-P and CMT, using the AUTROD 12.51 filler wire, to study their influence on the fume and gases produced during welding. The study aimed at analysing the fume formation rate and gas concentration in order to assess the process with best features in terms of health and safety at work.

With the purpose of analysing the influence of NO additions on the fume and gases emitted during arc welding, two shielding gas mixtures were also studied, Ar+8%CO_2 and Ar+8%CO_2+0.03%NO. Shielding gas mixtures are used to protect the welding area from the deleterious effects of atmospheric gases.

It was also the purpose of this work to analyse the influence of different filler wires on fume generation rate, using GMAW. In this context, the following wires were tested: AUTROD 12.50 without Cu; AUTROD 12.51 containing copper in its covering; fluxed cored SAFDUAL Green 201 and SAFDUAL Green 207.

Afterwards, two wires were selected, SAFDUAL Green 207 and AUTROD 12.51, for an in depth analysis of shielding gas mixtures on fume formation rate, using the GMAW process. Five different shielding gas mixtures were tested, for that purpose, namely: Ar+10%CO_2; Ar+18%CO_2; Ar+5%CO_2+4%O_2; Ar+13%CO_2+4%O_2 and Ar+10% CO_2+30%He. Filler wires compositions are shown on Tables 1 and 2.

In order to study the fumes and gases produced during welding, bead-on-plate welds were made, in steel plates of 6 mm thickness (see composition in Table 3), within a range of welding current intensity from 36 to 80A for a wire of 0.8 mm, and from 75 to 300A for 1.2 mm wire. Within this range, the parameters were chosen so that acceptable quality welds could be obtained for each of the studied cases, thus allowing comparison between shielding mixtures and processes. Lower current values are important to compare low energy variants, as CMT and GMAW-P, with GMAW, while higher values of current are needed to compare consumables in order to cover the range of parameters used for root and thin pass welds as well as filler welds. Test conditions are shown on Table 4.

Table 1 AUTROD filler wires typical weld metal chemical composition

Filler wires	C (%)	Mn (%)	Si (%)
AUTROD 12.50	0.1	1.5	0.9
AUTROD 12.51	0.1	1.5	0.0

Table 2 SAFDUAL filler wires typical weld metal chemical composition

Filler wires	C (%)	P (%)	S (%)	Mn (%)	Si (%)
SAFDUAL Green 201	0.05	0.011	0.014	1.5	0.6
SAFDUAL Green 207	0.05	0.01	0.08	1.68	0.86

An electrode wire of 1.2 mm was used, except for the study which envisages a comparison between CMT, GMAW and GMAW-P, were an electrode wire of 0.8 mm was used instead, as it allows to weld with lower current levels typical of the CMT process.

A power supply Fronius—Transpulse Synergic 4000 was used to conduct the study. The torch was maintained on a simple mechanised system. A computer equipped with an analogue-to-digital (A/D) conversion board was used to sample the current, the voltage and the wire feed speed during welding.

Fume formation rate (FFR) and gases emissions were measured using the standard procedures described in EN ISO 15011-2 [1]. For this, a fume chamber was built (Fig. 2). A turntable was used, upon which the plates were fixed. The air flow rate through the fume chamber was 100 m^3/h.

The fume emitted was collected on pre-weighted glass fibre filtres with a 240 mm diameter (Whatman GF/A) which were then re-weighted to give the total weight of fumes produced. The weight was then used along with the arc time to calculate FFR. In these experiments, arc time employed was 60 s. For the purpose of this work, the FFR is defined as the weight of fume generated per unit of arcing time and is quoted in grams per minute. Before being used, the filtres were heated during 1 h at 150°C, for complete dryness.

To obtain a more accurate and consistent result, each test was made three times, and the results presented are the average of these measurements.

Relative to gas concentrations a similar procedure was followed. To measure CO and NO_x emissions a Testo 350-S flue gas analyser was used. The probe was placed as shown in Fig. 3.

3 Results and discussion

3.1 Influence of NO addition to the shielding gas

The reduction of fume emissions at source is of extreme importance since the effective control of fumes emitted during welding, through general and local extraction, is not always adequate. The magnitude of the hazard created by welding fumes depends on the composition and concentration of the fumes and gases and on the exposure time.

Table 3 Base metal composition of 6 mm thickness

Base metal	C (%)	P (%)	S (%)	Mn (%)	Si (%)
(Steel St52.3)	0.2	0.035	0.035	1.6	0.55

Table 4 Welding parameters used for experimental tests

Parameters	1.2mm wire	0.8mm wire
Current [A]	From 75 to 300	From 36 to 80
Voltage [V]	From 10 to 28	From 10.1 to 22.7
Wire feed speed [m/min]	1.4 to 7.7	1.7 to 10.5
Welding speed [mm/min]	470	470
Gas flow [l/min]	15	15
Electrode's extension [mm]	13	13

Figure 4 represents the evolution of fume formation rate with the current intensity for the Ar+8%CO_2 and Ar+8% CO_2+0.03%NO shielding gas mixtures, produced during CMT welding.

The trend of the curves is similar for both mixtures. Globally, the figure indicates that the fume formation rate increases with current intensity, being the slope of the curve more accentuated for current intensities higher than 200 A. This increase is related, not only to the higher arc temperature, but also to the fact of CMT has been used with current intensity levels higher than the ones advised by the manufacturer for this low current GMAW variant. This can lead to different phenomena, namely arc instabilities which influence negatively fume generation. This procedure was used for the sake of having comparable results with the different GMAW variants.

From Fig. 4, it can also be seen that when NO is added to the shielding gas mixture the fume formation rate also increases, although that difference is not important. Similar results were obtained with the GMAW process.

The short increment of fume formation rate, with NO addition might be related to a more unstable electric arc,

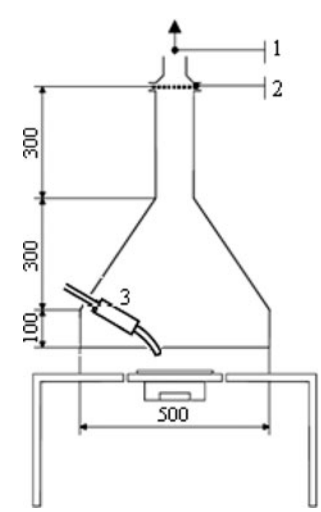


Fig. 2 Fume chamber used in the experimental procedure, where *1* air flow probe, *2* fibre filtre, *3* welding gun fixture (dimensions in mm) [1]

Fig. 3 Fume chamber prepared for gas emissions analysis, illustration the Testo 350-S flue gas analyser

which promotes spatter, as well as to an increase of the oxidising content of the mixture that increases the arc temperature as a result of the exothermic reactions between oxidising elements and the weld pool elements. It should be noted, however, that due to the small amount of NO added; only 0.03%, this phenomena only happens in a small extent.

Relative to the gas concentration seen in Fig. 5, which represents CO, NO and NO_2 concentration with current intensity, the CO concentration is identical for both mixtures, and that this value increases with the increase of current intensity, being at approximately 200 A above the reference exposure limit for this substance.

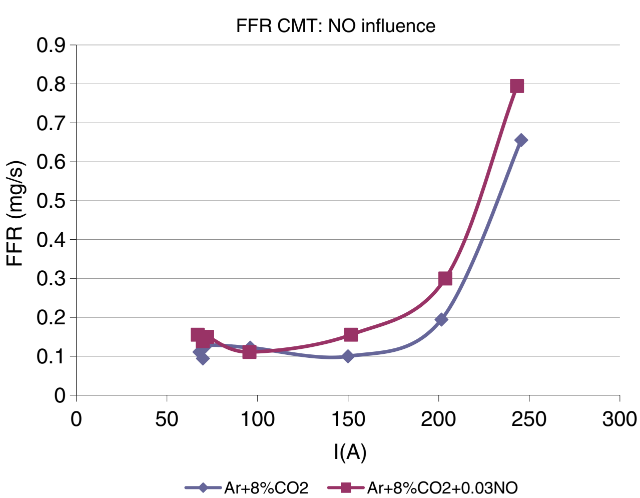


Fig. 4 Variation of fume formation rate with the current intensity for Ar+8%CO_2 and Ar+8%CO_2+0.03%NO shielding gas mixtures, with CMT

In what concerns the nitrogen oxides concentration it can be seen that NO and NO_2 mixtures are below the reference exposures limits [14].

The CO concentration is related with the CO_2 content of the shielding gas mixture, and increases with the increase of ultraviolet radiation, due to the CO_2 decomposition. CO emissions might also result from oxidation and evaporation of carbon from the base material and welding wire although further experimentation needs to be carried out to confirm this. It should be noted that for current levels above 200 A the CO emissions exceeded the exposure limit for 8 h reference period for that gas [14]. Thus, actions need be taken in order to reduce these values. This can be achieved by improvement of ventilation, use of welding helmets with air ventilation or fume sensors and reduce CO_2 content in shielding gas.

In what concerns emissions of nitrogen oxides it can be seen that NO_2 emission are higher using Ar+CO_2+0.03% NO as shielding gas. This result, as well as the results of fume emissions, indicates that NO addition does not bring any benefit in terms of the quality of the environment for the welder.

3.2 GMAW versus CMT

CMT and GMAW fume emissions can be observed in Fig. 6, which represents the evolution of fume formation rate with current intensity for the two welding processes referred, Fig. 6 shows that GMAW leads to higher fume formation rate comparatively to CMT.

As referred previously, fume formation rate increases with current intensity, which can also be seen in Fig. 6.

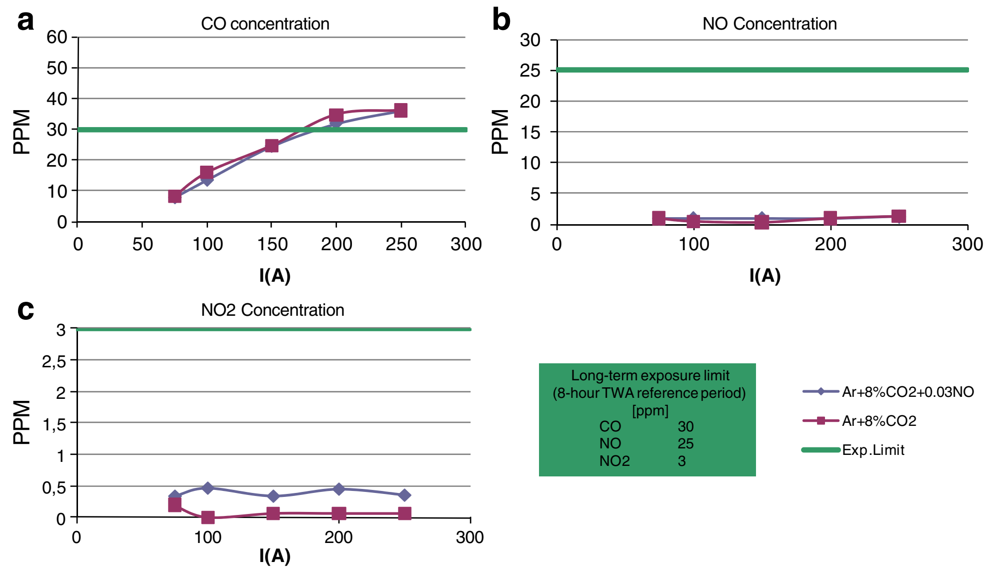


Fig. 5 Variation of gases emissions with the current intensity for Ar+8%CO_2 and Ar+8%CO_2+0.03%NO shielding gas mixtures, with CMT. **a** CO concentration, **b** NO concentration and **c** NO_2 concentration. The long-term exposure limited for each analysed gas is also indicated in the figure

These results give an indication that CMT generates lower fumes during welding comparatively to GMAW, and that a correct parameter configuration is essential to reduce harmful emissions.

GMAW leads to higher fume formation rate comparatively to CMT. This result is essentially related to the fact that the CMT process is used with heat inputs substantially reduced compared to GMAW and is virtually spatter-free. To lower heat inputs corresponds lower arc temperature and consequently lower heating and evaporation. To less spatter (i.e. projection of small particles) corresponds less material that is projected for regions outside the influence of shielding gas that are oxidised and vaporised.

As referred previously fume formation rate increases with current intensity. However, fume formation rate is also related to metal transfer modes. In CMT the metal transfer mode is always a controlled short circuit, independent of the current intensity, so fume formation rate should increase progressively with its increase. Nevertheless, there is a substantial increase of fume emitted for currents levels above 200 A, which might be related to the fact of this process has been developed to be used for lower current intensities. Using higher currents causes some arc instability and consequently higher fume emissions.

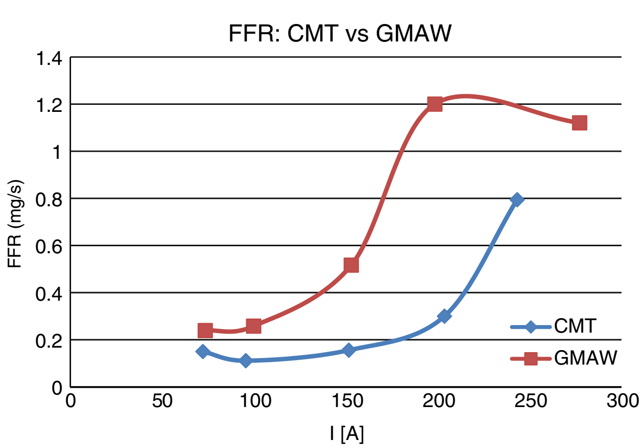


Fig. 6 Variation of fume formation rate for CMT and GMAW with the current intensity, using Ar+8%CO_2+0.03%NO as shielding gas mixture and a 1.2 mm, AUTROD 12.50, filler wire

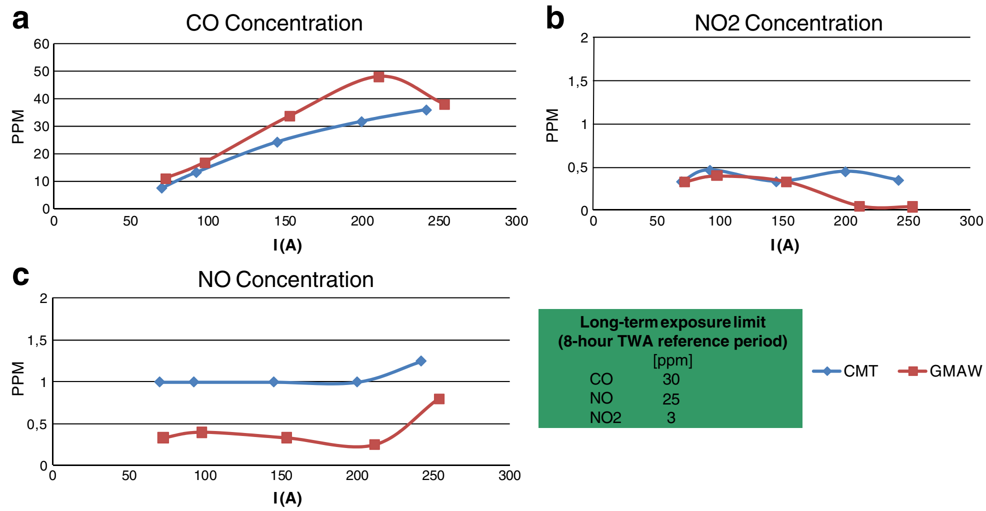
In what regards GMAW, metal transfer modes vary with the increase of current intensity, ranging from short circuit to globular and spray. Consequently, the fume formation rate increase with current intensity is not linear and there is a decay in that value for current intensities around 200 A. This decay is related to the change from an unstable transfer mode, globular, to a more stable one, i.e. spray. If more tests were done for higher current intensities fume emissions should continue to increase again, this time due to the temperature increase.

The results of gas concentration indicate that CO emissions are higher for GMAW comparatively to CMT, although both are above the reference exposure limit, for current intensities higher than 120 A.

Nitrogen oxides are created due to the turbulent flow of the shielding gas in contact with hot metal sheet, due to the CMT process characteristics it promotes an increase of shielding gas mixture turbulence in the shielding zone, comparatively to GMAW, which leads to an increase of nitrogen oxide emissions, as it can be observed in Fig. 7.

CO concentrations are higher for GMAW comparatively to CMT due to the higher heat input and ultraviolet radiation associated with the former process. NO and NO_2 are generated as by-products in most arc welding processes as a result of the heating of air in the arc. High

Fig. 7 Variation of gases emissions with the current intensity for CMT and GMA, using Ar+8%CO_2+0.03%NO as shielding gas mixture, and a 1.2 mm, AUTROD 12.50, filler wire. **a** CO concentration, **b** NO concentration and **c** NO_2 concentration



temperatures cause the oxidation of nitrogen in the air according to [7]:

$$N_2 + O_2 \leftrightarrow 2NO \tag{1}$$

$$N_2 + 2O_2 \leftrightarrow 2NO_2 \tag{2}$$

At low temperatures both reactions are displaced far to the left but when the temperature increases, in particular to temperatures above 500–1,000°C, the oxidation of nitrogen in the air increases strongly. Furthermore, the relative NO/NO_2 formation ratio increases with the temperature, i.e. the NO formation increases relatively compared to the NO_2 formation, according to the mass balance [7]:

$$2[NO_2] \leftrightarrow 2[NO] + [O_2] \tag{3}$$

The increase in NO_x emission rate as well as the change in NO/NO_2 ratio, observed in Fig. 7, can be explained by the larger volume of air heated and the heating temperatures.

Nitrogen oxides are created due to the turbulent flow of the shielding gas in contact with hot metal sheets: the surrounding air is mixed with the shielding gas near the protection boundary and nitrogen becomes monatomic (due to the arc's influence) and blends with oxygen to create NO and NO_2. In CMT welding process the electrode wire is moved forwards and backwards—once short circuit has happened, resulting in electric arc discontinuities (i.e. successive arc extinction and reignition). This process characteristic promotes an increase of shielding gas mixture turbulence in the shielding zone, comparatively to GMAW, which leads to an increase of nitrogen oxide emissions.

3.3 GMAW versus GMAW-P and CMT

The results of fume formation rate with current intensity for the three welding process in study are represented in Fig. 8. The welding tests were made, in this case, with low values of current intensity, in order to simulate the conditions used in practise for these new variants, especially CMT. Under these circumstances all processes operate in short circuit metal transfer mode, although for CMT and GMAW-P this transfer mode is controlled.

The pattern of the CMT and GMAW-P curves represented in Fig. 8 is similar. From the same figure it is possible to observe that fume formation rates are superior in GMAW comparatively to CMT and GMAW-P.

This result is related not only to the higher heat inputs, but also to the higher levels of spatter resultant of the lower arc stability associated with the short circuit transfer mode in GMAW, as within these welding tests all processes operate in short circuit metal transfer mode, although for CMT and GMAW-P this transfer mode is controlled.

It can be concluded that from the three processes studied the CMT and GMAW-P exhibited the lowest and

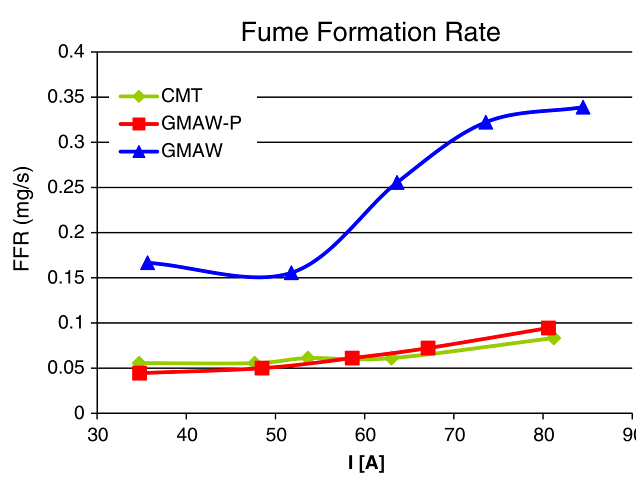


Fig. 8 Variation of fume formation rate for CMT, GMAW-P and GMAW with the current intensity, using Ar+8%CO_2 as shielding gas mixture and a 0.8 mm, AUTROD 12.50

similar fume formation rate, while GMAW produced the highest.

Figure 9 illustrates the results of gases concentration during CMT, GMAW and GMAW-P welding tests. For the current levels used during these welding trials the gas emissions are below the reference exposure limits.

Relatively to the gases concentration, for GMAW-P, the same observations already made for CMT can be assumed.

3.4 Influence of filler wire

To analyse the influence of different types of filler wires on fumes produced during GMAW, four C-Mn steel wires were selected.

The results of these tests are presented in terms of fume generation rate (FGR) instead of fume formation rate. The adoption of such unit of measure was necessary to make possible the comparison of the results between cored (green) wires and solid wires. The adoption of other units of measure, like [mg/s] or [g/min], normally adopted in the case of solid wires would not be appropriate, as the efficiencies of deposition of a solid wire and a cored one are totally different. From the above, time is not a valid parameter to allow a reliable comparison, thus FGR value in (mg of formed fumes)/(kg of deposited material) was used.

In order to calculate the fume generation rates [mg/kg filler metal deposit] the following expression was used:

$$FGR_{fume} = M_{fume}/M_{filler\ metal}, [mg/kg] \quad (4)$$

where:

M_{fume} Mass of fume, [mg]
$M_{filler\ metal}$ Mass of filler metal-deposit, [kg]

The calculation of the mass of the deposited metal was done according to the expression:

$$M_{filler\ metal} = V_{wire} \cdot \gamma .10 - 3, [kg] \quad (5)$$

where:

$M_{filler\ metal}$ Mass of filler metal-deposit, [kg]
V_{wire} Volume of wire (filler metal used in test), [dm^3]
γ Weight by volume, [kg/m^3] and

$$v_{wire} = \frac{\pi d^2}{4} * v * t * 10^{-3}, \quad [dm^3] \quad (6)$$

where, d is the wire diameter, mm; v is the wire speed, m/s and t the time of test, s.

Figure 10 represents a comparison of the fume generation rate with current intensity for different filler wires.

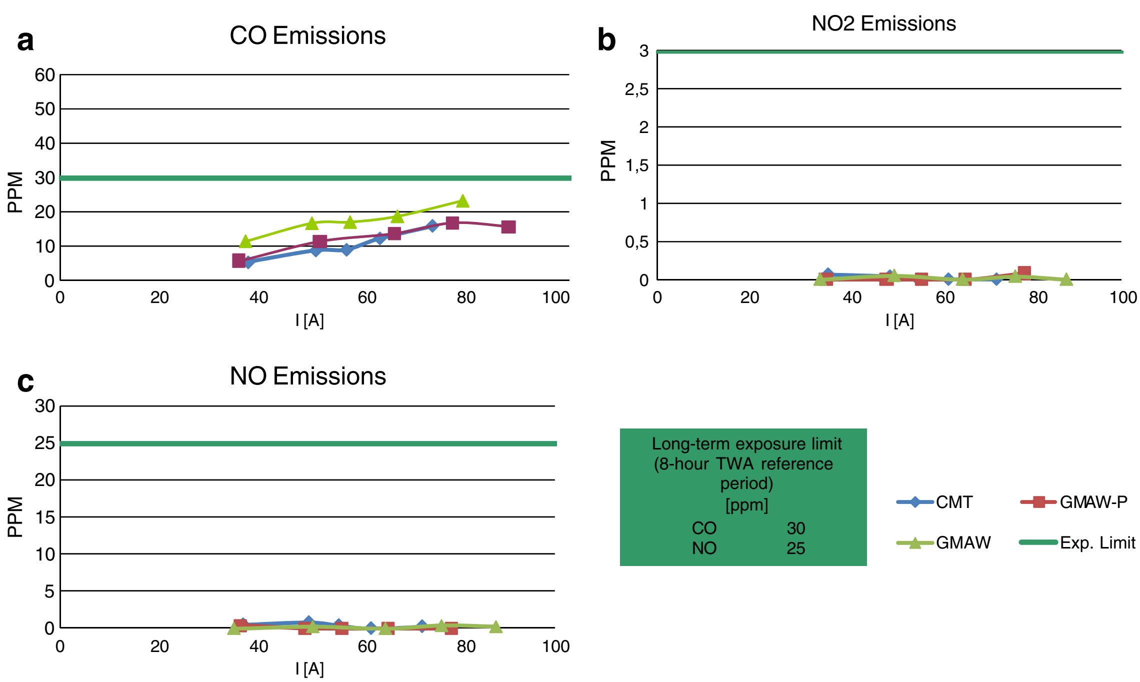


Fig. 9 Variation of gases emissions with the current intensity for CMT GMAW-P and GMA, using Ar+8%CO_2NO as shielding gas mixture and a 0.8 mm, AUTROD 12.50. **a** CO concentration, **b** NO concentration and **c** NO_2 concentration. The long-term exposure limited for each analysed gas is also indicated

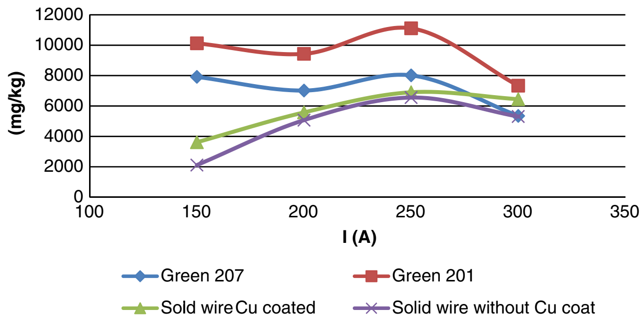


Fig. 10 Influence of filler wires on fume generation rate, using Ar +10%CO_2 as shielding gas

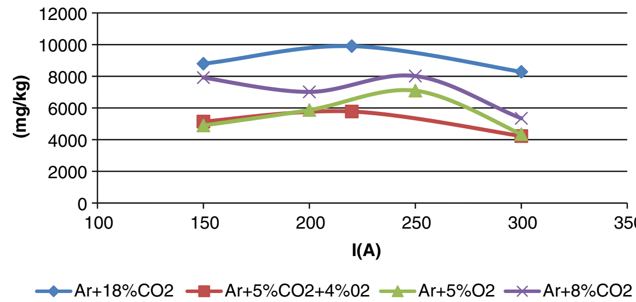


Fig. 11 Influence of shielding gas mixtures on fume formation rate, using filler wire Safdual green 207

By observation of the results the following considerations may be drawn:

- As a general remark it may be observed that the results are significantly scattered. Furthermore, it is possible to notice that the FGR does not always follow similar trend since low FGR values are observed both at low as well as at high current values. The peaks are observed, as expected, for values around the spray transition current.
- For higher values of welding current (300 A) it can also be noticed that the "green" wires do not generate significantly more fumes than the solid wires.
- In the case of the solid wire, 12.50, without Cu in its covering is possible to notice a quite low value of FGR (2.000 mg/kg), in particular at low current level (140 A).
- Also the solid wire 12.51 containing copper in its covering showed a very good FGR value (3.900 mg/kg deposit), for the lower welding current intensity.
- Relative to the fluxed cored wires green 201 leads to higher FGR comparatively to the green 207, although that difference is reduced.
- The removal of copper coat has not significant influence in fume emission rate.
- The fume generation rate peak at 250 A is consistent and is related with the transition current from globular to spray.

3.5 Influence of shireding gases

In order to study the influence of shielding gas mixture two sets of experiments were made; one using a metal green wire and the other using a solid wire coated with copper.

The results obtained with the cored wire (green 207), using different shielding gas mixtures are illustrated in Fig. 11.

Globally, the figure indicates that the fume generation does not always follow a similar trend. In order to achieve smaller fume formation rates with high productivity, the user can decide on cored wires and binary gas mixtures. Minimum values can be achieved by reducing the CO_2 content in the mixtures and using metal cored wires, which lead to FFR very similar to solid wires and higher productivities.

Relative to the solid wire with copper coat, the results of fume formation rate are summarised in Fig. 12.

Shielding gas mixtures with higher CO_2 contents leads to higher fume generation rates. This fact is related to:

- Decrease of arc stability. There is a higher amount of spatter released during welding, which is projected for regions outside the influence of the shielding gas and are oxidised and vaporised.
- Increase of thermal conductivity of the mixture, which promotes a reduction of the conduction zone, being almost all the generated heat concentrated in that region. Therefore, there is a local and intense heating of the molten droplet that enters rapidly in ebullition.
- Increase of the active (CO_2) content of the mixture. When the amount of carbon dioxide in the mixture increases, the reaction rate that occurs in the weld pool also increases. This is the result of the decomposition of CO_2 into CO and O_2.
- Oxidising content of the mixture. This increases the arc temperature as a result of the exothermic reactions between oxidising elements and the weld pool elements.

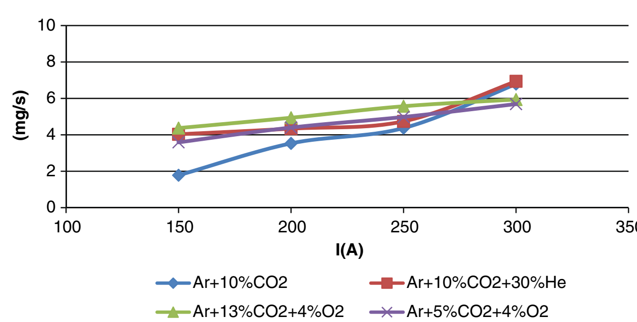


Fig. 12 Influence of shielding gas mixtures on fume formation rate, using filler wire Autrod 12.51 with Cu coat

The FGR values are greatly scattered independent of the combination wire (green i.e.: flux cored, or solid with or without Cu in the cover) and shielding gas mixture (binary with different contents of active gas, CO_2 or O_2, or ternary).

It can also be noticed that the positive effect of the green (cored) wires, in terms of reduction of FGR values, is stronger at the higher values of welding current (300 A) and it is also reasonable to expect that this might further be reduced if the current would increase.

4 Conclusions

Control of fumes at the source, by modification of process, procedures and/or consumables, can be used to complement existing control strategies. A systematic approach to fume control by GMAW process modification contributes to a reduction and clarification of fume emission and will support on making decisions to provide a healthier environment for welders.

This paper attempts to point out ways of reducing the potential harmful effects of gas metal arc welding processes. The data presented gives a summary of the different gas metal arc welding procedures and their relations to fume generation rates and gases emitted. The results obtained have shown that:

- The fume formation rate is closely dependent on the welding parameters. By selecting the right welding parameters, namely the welding current intensity, FFR can be reduced.
- In general, fume formation rate increases with welding current intensity, with exception of the transition current range, where short circuit/globular to spray transfer occurs.

Relative to GMAW variants:

- The fume formation rate decreases with the arc stability and with the decrease of arc temperature. Therefore, CMT and GMAW-P leads to lower fume formation rates comparatively to GMAW.
- CO emissions increase with the increase of heat input and arc temperature. Therefore, CMT and GMAW-P lead to lower CO emissions comparatively to GMAW.
- Nitrogen oxides increase with the turbulent flow of the shielding gas in contact with hot metal sheet. Therefore, the CMT process generates higher emissions of these compounds.

Relative to the shielding gas mixtures:

- The NO addition to the shielding gas mixtures also affects FFR and nitrogen oxide emission. The fume formation rate increases and nitrogen oxides emissions increase with the addition of NO to the shielding gas.
- The fume formation rate increases with the increase of CO_2 and O_2 in the mixture.

Relative to the filler wires:

- Metal cored or solid wires with shielding gas mixtures with low CO_2 content gives rise to lower fume emissions.
- "Green" wires are quite "environmentally friendly", leading to lower emissions than more conventional fluxed cored wires.
- For solid wire with or without copper cover no significant differences were observed, although FGR with the wire without Cu cover were slightly lower.

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