INFLUENCE OF THE SHIELDING GAS COMPOSITION ON THE MORPHOLOGY AND ARC STABILITY IN GMA WELDING OF THE ASTM A516 STEEL

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Abstract *The GMAW process (Gas Metal Arc Welding) has been widely used in the mechanical industry, for their characteristics of high productivity, quality and low cost. However, specifically in the production of pressure vessels, the use of this process has been limited, because the produced welds do not reach the requirements imposed by the standards. In most of cases, the GMAW process do not comply with the morphology and mechanical properties for pressure vessels production. This work aims at studying the influence of the composition of mixtures of protection gases in the morphology of welds deposited in the ASTM A516 steel degree 70 for the GMAW process. In this research three shielding mixtures are proposed containing amounts varied of argon, helium,* CO_2 *and oxygen. Three weld beads were deposited on steel plates ASTM A516 degree 70 for each composition of tested shielding mixture. The transverse sections were prepared for the analysis macrographic, where it was determined the dimensions of the reinforcement, width and penetration of the weld bead, as well as the area of the melted zone. The electric parameters were monitored during the tests, showing larger current variations in function of the time for two mixtures containing helium. The obtained results have shown larger penetration, height and area of the melted zone in the weld beads accomplished with the shielding gas based in argon and* CO_2*. All the three used gaseous mixtures resulted in a form of centralized penetration.*

1. Introduction

The GMAW process (Gas Metal Arc Welding) has been widely used in the mechanical industry, due to their characteristics of high productivity, quality and low cost, replacing the welding process with covered electrodes (SMAW) in several applications (Liao and Chen, 1998). However, specifically when manufacturing pressure vessels, the use of this process presents limitations, since the welds do not reach the requirements imposed by the standards. In most of the cases, the GMAW process does not afford aceptable morphology and mechanical properties for pressure vessels production (Okumura and Taniguchi, 1982).

Pressure vessels are metallic structures subject to high loads and demand welds with strict reliability degree. They are manufactured with SMAW process, which meets specified requirements. However, the drawback occurs in the final cost of the product, due to intrinsic characteristics of the process, such as low productivity and the need of special attention with certain types of electrodes. SMAW produces welds with good metallurgical characteristics and appropriate morphology. To increase the competitiveness in this industry, the GMAW process has been examined as an alternative to improve the productivity in the welding of pressure vessels. It has been demonstrated by several researchers (Dillenbeck and Castagno, 1987; Lyttle and Stapon, 1990 and Pereira and Ferraresi, 1998) the existence of problems, such as: lack of penetration in the root of the weld and lack of fusion in the multi-pass welding. These defects can result in catastrophic flaws of the equipment.

In the GMAW process, the weld pool, the electric arc and the filler metal transferred for the weld are protected from contacting the atmosphere by a laminar flow of gas, that besides housing the area that is being welded from contamination by the atmosphere, exercises an outstanding influence in: the stability of the welding process; the operational characteristics, the geometric characteristics of the weld bead and the properties of the deposited metal. Hence, the type of gas employed constitutes an important variable for the quality determination of the weld and in the productivity of the process (AWS,1991).

According to Marques, Modenesi and Valente (1998), the physical and chemical properties of the gases, such as ionization potential, thermal conductivity, chemical reactivity with the base metal, among others, determine the operational characteristics of the welding arc and the properties of the produced welds. Like this, parameters as the operation tension, the generated heat, the thermal profile and the efficiency of the arc, that affect the morphology of the weld bead, are strongly influenced by the chemical composition of the shielding gas.

Linnert (1994) defines the ionization potential as the total energy, in electron volts (eV), necessary to extract one electron of an atom or molecule and put it in rest in an infinite distance. In agreement with the literature (AWS, 1991; Jönsson, Eagar and Szekely, 1995 and Vaidya, 2002), although the argon and the helium are both inert gases, their physical properties are markedly dissimilar. The argon gas possesses lower ionization potential (15,755 eV) when compared with helium (24,580 eV), allowing an easy arc starting as well as great stability. However, for an identical welding current, arc voltage is larger with helium than with argon, because helium is a gas of high ionization potential, resulting in larger generation of welding energy, but a harder-to-start and less stable arc.

According to Lyttle and Stapon (1990); Suban and Tusek (2001) and Vaidya (2002), the thermal conductivity of the shielding gas is an important physical property, that is related with the amount of heat transferred by welding arc, which will influence the metal transfer and the morphology of the weld bead. Shielding with high thermal conductivity as the helium and the carbon dioxide drive the heat largely in the radial direction, making the plasma column to expand, originating a bell format, also tending to reduce the height of the plasma column. The temperature gradient among the central and peripheric area of the plasma column is smaller, if compared with a shielding gas with low thermal conductivity, like argon, resulting in a higher penetration, evenly distributed in the weld bead.

Figure 1 shows the behavior of the thermal conductivity, in function of the temperature, of some gases that are of interest for the study of the GMAW process.

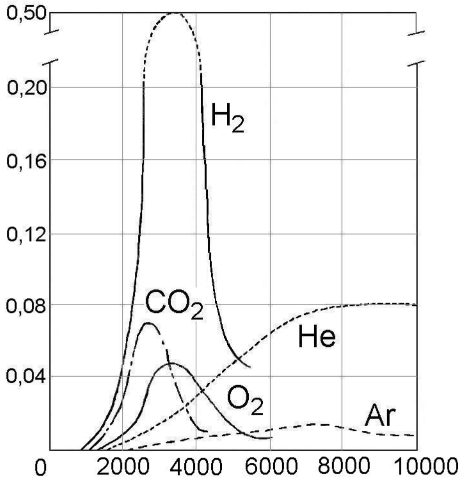

Figure 1. Thermal condutctivity of gases as a function of temperature (Suban and Tusek, 2001)

The diagram of fig. 1 show that the molecular gases (H_2; CO_2; O_2) present higher thermal conductivity than the monoatomic gases like Ar and He, for a temperature range of approximately 3000 ^oC, where the higher values of thermal conductivity are registered, caused by the dissociation of the molecular gases to the atomic form. The helium presents larger thermal conductivity than the argon in all considered temperature width. Among the shielding gases used in the GMAW process, the argon is the one that presents smaller thermal conductivity for any temperature band of the arc (Suban and Tusek, 2001; AWS, 2001).

As mentioned by Quintino and Pires (1996), the binary, ternary, or even quaternary mixtures, commercially used for industrial applications of welding, are supplied by specialized companies, which offer a very small range of products. The preparation of the shielding mixtures has been an almost exclusive activity of these companies, that limits the research possibilities in this field.

The object of study in this work is to examine the influence of the composition of mixtures of shielding gases in the GMAW of the ASTM A516 steel, which is recommended for services in moderate and low temperatures, presenting the supplemental mechanical property of tenacity. It is largely used for production of pressure vessels, mainly when concerning with the geometry of the weld bead and stability of the electric arc.

2. Experimental procedure

In this research the use of three shielding mixtures is proposed, containing a combination of controlled amounts of argon, helium, CO_2 and oxygen, with the predominance of gas argon in the mixtures. This is to allow better stability to the electric arc of welding. As quoted by the literature (Dillenbeck and Castagno, 1987; AWS, 1991 and Vaidya, 2002), the use of a shielding mixture containing helium and/or carbon dioxide results in a weld bead with deeper penetration and uniform fusion in the weld, in function of the high thermal conductivity of those gases.

The base metal used in this work has been the ASTM A516 degree 70 steel. This material is commonly used for the production of pressure vessels, being a steel that conforms to the toughness requirements in moderate services and low temperature, where the graduation 70 of this specification corresponds to 70000 PSI of minimum tensile strength. Tab. 1 lists the chemical composition of this material.

Table 1. Chemical composition of the ASTM A516 steel, degree 70 (wt%).

Especification	Maximum %C for $t^{(1)}$ (mm)				Mn	Si	P máx.	S máx.
	$6 \leq t \leq 12.5$	$12.5 < t \leq 25$	$25 < t \leq 50$	$50 < t \leq 63$				
ASTM A516 degree 70	0.27	0.28	0.28	0.30	0.85 - 1.20	0.15 - 0.40	0.035	0.035

(1): thickness of the plate

For the accomplishment of this investigation, an INVERSAL 450 multiprocess welder was used, operating with voltage imposition, connected with a data acquisition system that uses a dedicated software. This system acquires instantaneouslly values of current and voltage, allowing the evaluation of the electric arc stability during the weldings.

The three shielding mixtures proposed for this research were named as: M1 (Ar+20%CO_2); M2 (Ar+15%He+5%CO_2); M3 (Ar+18%He+2%O_2).

The filler material used was the welding wire of diameter 1.2 mm, classification AWS ER70S-6.

To study the influence of the composition of the shielding gas in the welding of the ASTM A516 steel (morphology of the weld bead and stability of the electric arc), a relationship was established among the influence variables in the GMAW process, to impose the shielding gas as the only variable. The wire feed speed (Va), voltage (U), welding speed (Vs), distance of the contact tip to piece (DBCP), the inductive effect (Inductance) and flow of the shielding gas (Vgas), were adjusted in pre-tests and are presented in Tab. 2.

Table 2. Fixed welding parameters used in the experiments.

Va (m/min)	U (V)	Vs (cm/min)	DBCP (mm)	Inductance	Vgas (l/min)
7.5	24	35	16	5	14

The welding parameters, shown in Tab. 2, allowed the short circuit metal transfer, for the three used shielding mixtures.

The depositions of weld beads were executed in an automatic way, using a displacement system of the welding torch to ensure the determination of the heat inputs of the tests and the repeatability of the samples. Each weld was monitored by the data acquisition system, that genereted an oscilogram for each one.

A centralized weld bead was deposited on the longitudinal sense, on each workpieces of ASTM A516 steel degree 70 used (50 x 150 x 9,525 mm), for each composition of tested shielding mixture.

The workpieces were transversely cut using a metallographic sample cutter, 50 mm after the beginning of the weld bead. Adicionally two samples, spaced by 20 mm, were cut for each workpiece, forming a group of three samples for the weld bead. Those samples were prepared through grinding and chemical etching with a solution of nitric acid and alcohol (NITAL 10%).

The macrographic analysis of the sections of the weld bead were conducted by using an image analyzer equipment coupled in a metallographic bench with maximum enlargement of 10X.

3. Results and discussions

3.1. Arc stability

The influence of the composition of the shielding gas in the arc stability was analyzed through the acquisition of the current values during the weld depositions, considering the three tested shielding mixtures, as shown in Fig. 2. The obtained data from the analysis of the oscillograms are presented in Tab. 3.

In the three oscillograms presented in Fig. 2, the form of metal transfer was characterized as short circuit, where abrupt oscillations of the welding current can be observed (representing this way of metallic transfer).

For the mixture M1, the current in the oscillogram shown in Fig. 2 and Tab. 3 present a large number of short-circuits (38) for the analysed period (1second). The short-circuits may be identified graphically through the current peaks. When the mixture M2 was used, 31 short-circuits per second were observed and for the mixture M3 the number of short-circuits per second were 36. Having larger amount of current peaks for time interval, the welding current suffers fast oscillations, that can result in instability of the electric arc. However, when the mixture M1 was used, the maximum values of current wasn´t reached 400 A and the minimum values was not exceeded 200 A. In other words, the width of the oscillation of the welding current is smaller (229 A), resulting in a reduced standard deviation of the current (52,89), in relation to the mixtures M2 (70,34) and M3 (100,32). Thus, it is considered that there was a larger arc stability with the shielding mixture M1.

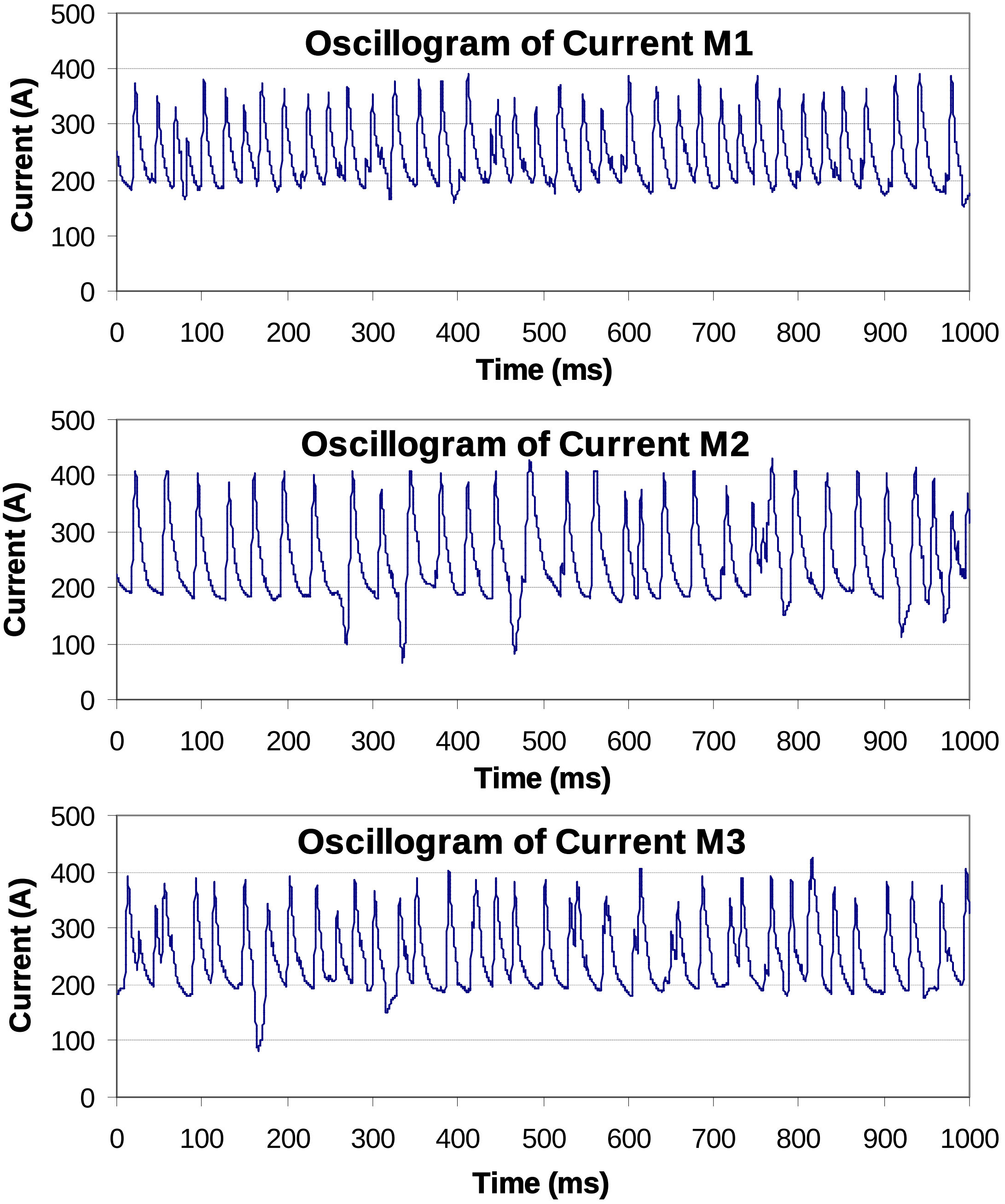

Figure 2. Oscillograms of current (A) in function of the time (ms) for three compositions of shielding mixtures: M1 (Ar+20%CO_2); M2 (Ar+15%He+5%CO_2) and M3 (Ar+18%He+2%O_2)

Table 3. Data of the current oscillograms for the tested shielding mixtures.

Shielding mixtures	M1 (Ar+20%CO_2)	M2 (Ar+15%He+5%CO_2)	M3 (Ar+18%He+2%O_2)
Medium current (A)	242	244	247
Minimum current (A)	159	67	83
Maximum current (A)	388	432	424
Width of the oscillation (A)	229	365	341
Standard deviation of the current	52.89	70.34	100.32
Short-circuits per second	38	31	36
Welding energy (J/cm)	9.956.57 (97.98%)	10038.86 (98.78%)	10162.29 (100%)

A similar interpretation, related to the arc stability, can also be inferred by comparing the width of the oscillation of the welding current, for the same period of considered time (1 second). Although the width of the oscillation of the current was larger for the mixture M2 (365 A) than for the mixture M3 (341 A), the standard deviation of the current for the mixture M2 was smaller (70,34) than for the mixture M3 (100,32), those were influenced by the amount of short-circuits, smaller for the mixture M2 (31), indicating higher arc stability for the mixture M2, and lower for the mixture M3.

Although all the welding parameters were maintained constant (except for the shielding mixture, in the operation mode used, voltage imposition), the medium current of welding suffered small variation, influencing the heat input, as shown in Tab. 3. Considering the mixture M3 as standard (100%), for presenting largest welding energy, it was verified that the percentual variation of the welding energy was approximately 2%, which does not impose significant effects in this research.

3.2. Morphology

A comparative analysis of the traverse sections of the welds is presented, obtained from the three tested shielding mixtures, to evaluate the influence of the composition of the shielding gas on the morphology of the weld bead.

Figure 3 presents the geometry of the traverse section of a weld bead, considered representative of this condition, obtained with the parameters mentioned previously in this work, in Tab. 2, using the shielding mixture M1 (Ar+20%CO_2). The suitable dimensions correspond to the reinforcement (2,842 mm), width (9,429 mm) and penetration of the weld bead (2,587 mm). In this macrographic analysis it is important to observe that the penetration form is centralized, known as finger type penetration. Despite this, it is observed that the fusion of the base metal wasn´t incomplete at the borders of the bead. The reinforcement of the bead presented semi-spherical form and without irregularities, showing good wettability offered by the gaseous mixture.

The low amount of CO_2 in the shielding mixture M1 (20%) justifies the centralized effect of penetration. According to Vaidya (2002), with predominance of the argon (80%), a low thermal conductivity gas, the temperature gradient between the central area of the electric arc and the outlying area is higher. Therefore, the largest amount of heat is concentrated in the radial direction, resulting in the obtained morphology.

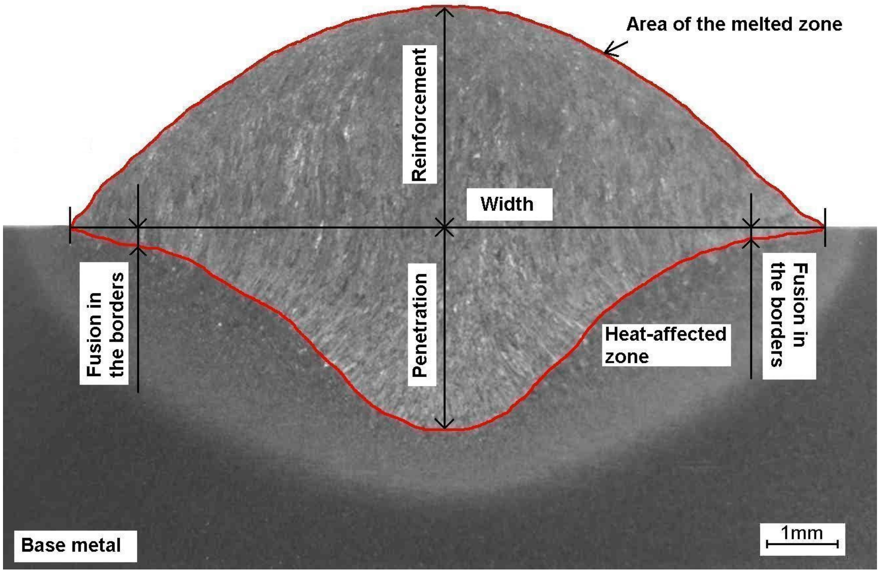

Figure 3. Traverse section of the weld bead using the mixture M1

Figure 4 presents the macrographic analysis of a weld bead obtained with the shielding mixture M2 (Ar+15%He+5%CO_2). The suitable dimensions correspond to the reinforcement (2,689 mm), width (9,055 mm) and penetration of the weld bead (2,281 mm). Also the penetration was finger type. However, the fusion in the borders of the weld bead was larger than obtained with the mixture M1. The reinforcement of the bead presented more convex form and with irregularities.

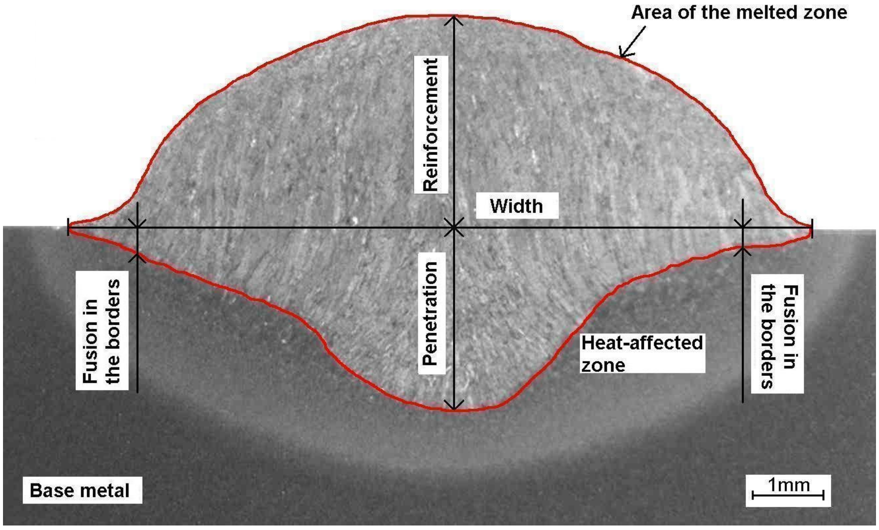

Figure 4. Traverse section of the weld bead using the mixture M2

In the mixture M2 the presence of the gas helium seemed to assure a better penetration profile, relatively to the mixture M1. It is believed that this occurs due to the high thermal conductivity of the helium in a wide range of temperatures in the atmosphere of the electric arc, as shown in Fig. 1, allowing a better distribution of the heat in the radial direction of the plasma column (Suban and Tusek, 2001).

Figure 5 presents the macrographic analysis of the weld bead accomplished with the gaseous mixture M3 ($Ar+18\%He+2\%O_2$). The dimensions illustrate the reinforcement (2,655 mm), width (9,685 mm) and penetration of the weld bead (1,940 mm). It was also observed the finger type penetration and better fusion of the base metal in the borders of the weld than obtained with the mixture M1. The reinforcement of the bead also presented more convex form, with irregularities, as well as in Fig. 4.

Simmilarlly well as in the welding using the mixture M2, the presence of helium in the mixture M3 seemed to assure a better penetration distributed profile, relatively to the mixture M1.

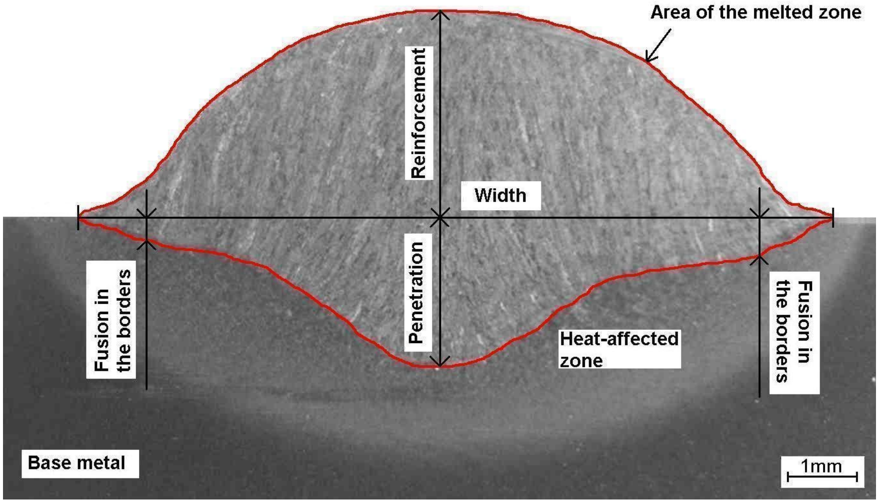

Figure 5. Traverse section of the weld bead using the mixture M3

Table 4 presents the medium values of the measures obtained in the traverse sections of the weld beads, for each composition of tested gaseous protection. A measurement of the total area of the melted zone and of the area of the melted zone below the surface of the plate was accomplished for a better evaluation of the penetration and the volume of the weld beads deposited.

Table 4. Medium values of the measures of the weld beads obtained with the tested shielding mixtures, considering the mixture M1 as standard (100%).

Shielding mixtures	M1 ($Ar+20\%CO_2$)	M2 ($Ar+15\%He+5\%CO_2$)	M3 ($Ar+18\%He+2\%O_2$)
Penetration (mm)	2.587	2.281 (88.17%)	1.940 (74.99%)
Width (mm)	9.429	9.055 (96.03%)	9.685 (102.71%)
Reinforcement (mm)	2.842	2.689 (94.62%)	2.655 (93.42%)
Penetration area (mm^2)	10.661	9.663 (90.64%)	8.636 (81.01%)
Melted total area (mm^2)	27.753	26.333 (94.88%)	25.123 (90.52%)

Analysing the values of Tab. 4, it can be observed that the samples obtained with the mixture M1 presented larger penetration, reinforcement, penetration area (that is considered as the area of the melted zone below the surface of the workpiece) and melted total area, what results in a larger deposition rate of wire electrode. According to Lyttle and Stapon (1990), due to dissociation and recombination of CO_2 in their components when used as shielding gas, larger heat transfer exists to the weld pool, that could justify the higher values obtained. The absence of CO_2 in the mixture M3 resulted in smaller penetration, smaller reinforcement of the bead and smaller melted area.

The variation of penetration area (in percentage), when comparing the values of penetration area obtained for the mixtures M1 (10,661 mm^2) and M3 (8,636 mm^2), was significant (approximately 19%), considering that the welding parameters were maintained constant. Although the variation of penetration area among the beads obtained with the mixtures M1 and M3 was considerable, the penetration profile obtained with the mixture M3, with larger amount of the gas helium (18%), was distributed in a more uniform way, as shown in Fig. 5, in comparison to the profiles showed in Figs. 3 and 4.

The weld beads obtained with the mixtures M2 and M3 presented reinforcement with larger convexity, as shown in Figs. 4 and 5. This can be related to the low oxidizing potential of those shielding mixtures. Weld beads with excessive convexity can result in lack of fusion in multi-pass welding, due to the formation of cavities among the adjacent beads, that could be difficult to fulfill by the passes of weld in the subsequent layer.

The weld depositions using the mixture M3, with larger amount of helium gas (18%), reached larger values of current (247 A), resulting in larger welding energy. However, smaller penetration and smaller area of melted zone were observed when this shielding mixture was used. It is believed that such result was obtained since the helium gas presents higher ionization potential, needing larger energy in the welding arc.

4. Conclusions

Considering the influences of the compositions on the proposed shielding mixtures, the morphology of the weld bead and the stability of the electric arc of GMAW process, the following conclusions may be drawn:

1. All the three shielding mixtures used resulted in a form of centralized penetration (finger).
2. The fusion of the base metal in the borders of the weld bead is larger when the shielding mixtures containing helium were used.
3. Larger penetration, reinforcement of the bead and area of the melted zone, were observed in the weld beads with the shielding gas $Ar+20\%CO_2$.
4. The current oscillograms registered larger variations of the current in function of the time for the two mixtures containing the gas helium.
5. The weld beads obtained with the shielding mixtures containing the gas helium presented reinforcement with larger convexity.
6. The composition of the shielding mixture of protection did not influence the medium current of welding significantly, when operating in the way of voltage imposition, for short circuit metal transfer.
7. Despite of the largest value of medium current, the shielding mixture with larger amount of helium (18%) presented smaller penetration and smaller area of melted zona, compared with the other used gaseous mixtures.

5. Acknowledgements

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