TRANSFER MODE / MECHANICAL PROPERTIES RELATIONSHIPS IN WELDED JOINT BY GMAW PROCESS

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Abstract. *The transfer mode / mechanical properties relationships have been studied in welded joint processed by GMAW. Considering the shielding gas contents used during welding were pure Argon (Ar), Argon (Ar) + 25% Carbon Dioxide (CO_2) and pure Carbon Dioxide (CO_2) the mechanical properties were available by tensile test. In this study a base metal ASTM A36 was welded with a filler metal ER70-S6 using the three gas mixtures. The results of this study showed that the transfer mode of the filler metal passes by globular mode, when welded with the pure Carbon Dioxide (CO_2), to spray mode if welded with (Ar + 25% CO_2) or the pure Argon (Ar). The microstructures associated with these different processes were characterized by optical microscopy (OM) and scanning electron microscopy (SEM). The microstructure of the welded joint by the pure Argon (Ar) revealed lack of penetration and a large density of voids. The microstructure of the welded joint by the mixture (Ar + 25% CO_2) revealed a small density of voids and a complete fusion in the root. The microstructure of the welded joint by the pure Carbon Dioxide (CO_2) revealed an intermediate density of voids in relation to the welded joints by the others shielding gases.The mechanical properties studied were microhardness and tensile strength. The results of the mechanical properties ratified the results obtained by the microstructural characterization. The best properties were obtained with the mixture (Ar + 25% CO2).*

Keywords: *GMAW processes, transfer mode, mechanical properties.*

1. INTRODUCTION

Welding has been used in a large scale of several industrial activities such as, automobile, petroleum and gas, aeronautic and marine industries. In all these cases there is a continuous search for improvement in the quality of the welded joints, such as pipes, pressure vessels, tanks and structural elements in these different industrial segments. In recent years, large investments have been made in research and development of welding processes and their characterizations to facilitate the selection of the most appropriate method for each specific application.

The semi-automatic Gas Metal Arc Welding (GMAW) is widely used due to its extensive range of application considering the thicknesses of the materials used. In addition GMAW has a high productivity when compared with the (SAW) shielded arc welding.

In this work, the influence of the shielding gas on the transfer mode of the filler metal will be studied, evaluating the microstructural characteristics and the mechanical properties of the welded joints by GMAW processes.

GMAW (Gas Metal Arc Welding) is a electric arc welding process in which the electrical arc is established between the base metal and the filler metal. In this process the wire (electrode) fed automatically and the shielding gas is responsible either for formation of the ionized field or protective atmosphere around weld pool.

In the welded area, where droplets molten are transferred through the arc to the fusion pool, protection against the oxidant effect of the atmosphere is required. This protection can be provided successfully by appropriate shielding gas, (Suban & Tusek, 2001).

Shielding gas can be inert, MIG process (metal inert gas), or active, MAG process (metal active gas).

In welding the shielding inert gas (MIG) can be Ar (Argon), He (Helium) or a rich controlled mixture of Ar supplemented with He, O_2 (oxygen) or CO_2 (carbon dioxide) at low levels. The inert gas does not react with the drop or the fusion pool, it acts only in the protection of these areas and assists in the opening and maintenance of the arc, (Quites, 2002).

In welding using an active gas (MAG) pure CO_2 or mixtures (Ar + CO_2 or Ar + CO_2 + O_2) can be used. Besides protection functions and electrical functions, the active gas reacts with the drop and the fusion pool, (Quites, 2002).

It's possible to cite as major variables in GMAW process: welding current intensity, type of polarity, voltage, wire feed speed, welding speed, type and characteristics of the energy source, shielding gas flow, arc length (stick out).

Basically there are four metal transfer modes in GMAW processes: globular (MIG and MAG); short-circuit (MIG and MAG); axial and rotational spray (MIG); and for pulsed arc (MIG), (Brandi, 1992).

• Globular transfer mode – It occurs for low current densities in which a shielding gas, especially CO_2 and helium are used (ASM, 1978). The drops of molten metal are transferred to the weld pool mainly by the action of the gravitational force, which limits the welding only in the flat position. The diameter of the drops is larger than the diameter of the wire. It is common in this transfer mode to occur lack of fusion, lack of penetration and spatters, (Quites, 2002).

• Short circuit transfer mode – It occurs for values of current lower than the globular transfer in which the active shielding gas mixture (CO_2 content > 15%) is used. When the drop is formed in the electrode tip, it touches the weld pool, forming a short circuit. This transfer mode is suitable for all positions and to weld thin plates because the penetration is not great. Nevertheless in this transfer mode there is the problem of spatter and arc instability (Brandi, 1992).

• Spray transfer mode – Came from the globular mode, if an increasing of the welding current is produced, the diameter of the metal drops whose are transferred to the piece decreases. At this moment, for a determined current range the transfer mode changes abruptly from globular to spray. The current in which this transfer mode changes is called transition current. For short arc lengths, the cord has a good finish and there is not any spatters (Modenesi & Nixon, 1994). This transfer mode is suitable for weld thick plates. The penetration is very high and the arc is very smooth (Brandi, 1992).

• Pulsed arc transfer mode - The transfer is of the axial spray type. The welding equipment generates two current levels: base current over this a peak current is applied which is higher than the transition current. This transfer mode has spray characteristic, but with a much lower average current. Thus, it's possible to weld in all positions (Brandi, 1992).

For all welding process the heat affected zone is exposed to thermal cycles and complex metallurgical transformations, producing in addition strains and residual stresses (Okumura & Taniguchi, 1982). The heat affected zone (HAZ), which depends on the welded material (base and filler metals), process and welding procedure, (Linert, 1967; Easterling, 1983).

The heat of the welding operation results in changes of temperature on the several points of a joint. The variation of temperature (T) versus time (t) is the thermal cycle at the considered point, (Zeemann & Emygdio, 2001).

All regions of the HAZ may change their properties in relation at the base metal due to thermal cycle. In general, the plus affected region is the coarse grains region, where the mechanical properties may be more affected, (Easterling, 1983; Modenesi et al, 1985).

2. MATERIALS AND METHODS

The samples used in this study were plates of ASTM A36 steel with dimensions of 201.00 mm X 37.60 mm X 6.35 mm. The filler metal used was the wire ER70-S6 (AWS A5.18 standard, 2001), with diameter of 1mm. The mechanical properties and chemical composition of the base metal, according to the Brazilian Center of the Construction in Steel (CBCA), and the filler metal, according to AWS A5.18 standard (2001), as shown in the Table 1.

Table 1 - Mechanical properties and chemical composition of the base metal and filler metal.

	ASTM A36	ER70-S6
%C	0.26 max.	0.18
%Mn	...(1)	1.75
%P	0.04 max.	0.03
%S	0.05 max.	0.03
%Si	0.40	0.90
%Ni	...	0.50
%Cr	...	0.20
%Mo	...	0.30
%Cu	0.202	0.35
%V	...	0.08
(%Nb + %V)	...	...
Yield Strenght (MPa)	250 min.	400
Tensile Strenght (MPa)	400-550	480
Elongation (%)	20 min.	22

The welding process used in this work was GMAW in which three commercial shielding gases were used: pure Argon (Ar), Stargold Plus mixture(75% Ar / 25% CO_2) and pure Carbon Dioxide (CO_2) .

The welding equipment used in this work was a source of tension that operates with the 20-320A current range and (DC) 15.5-44V open circuit voltage.

In the earlier of this experimental work preliminary tests were performed to find a average welding current higher than the current of transition, in order to get the metal transfer mode spray (aerosol) in the welding performed using Argon as shielding gas.

After the preliminary tests three experiments were performed as shown in the Table 2. In each experiment, plates of (ASTM A36) steel were welded, origining several samples for mechanical tests and microstructural characterizations.

Table 2 shows that the flow of the shielding gas, the average welding voltage and wire feed speed were kept constant in all experiments, while the average welding current and, consequently, the energy welding change due to the type of shielding gas used.

For measurement of welding parameters were used an analyzer of parameters and a pliers ammeter.

Table 2 – Welding parameters.

Experiment	**1**	**2**	**3**
Shielding Gas	(Ar)	(75% Ar / 25% CO_2)	(CO_2)
Gas Flow (l/min)	14	14	14
Medium Voltage (V)	24	24	24
Medium Current (A)	175	170	167
Wire Speed (mm/s)	112	112	112
Period (s)	33.81	33.81	33.81
Welding Energy (kJ/cm)	5.51	5.35	5.26

The welding process was performed on top joints with straight bevel in the flat position "1G" (AWS D1.1, 2002) and displacement in single direction. Plates were welded with root opening of 1.6 mm. Two passes, one of root and another of filling, were performed in each sample.

The Tensile tests were performed on a serf-hydraulic tensile machine with load cell of 100kN. In all tests a head displacement speed of 5.0 mm/min was used. The tensile tests were performed on transverse direction, where the longitudinal axis of the sample is perpendicular to the longitudinal axis of the welding cord, according to standard API 1104 (2007).

The microstructural characterization was performed by using of Scanning Electron Microscopy (SEM).

3. RESULTS AND DISCUSSIONS

3.1 Transfer Modes of the Filler Metal

Based on observation of the qualified welder by ABENDE / FBTS, the spray (aerosol) transfer mode of the filler metal was verified and obtained in the welding carried out either with the Ar or (Ar 75% / 25% CO_2). In the other hand the transfer mode of welding carried out with the CO_2 was globular. This result makes clear that the Ar, being a lighter gas, ionizes more easily than the CO_2. Being ionized more easily, the Ar potentiates the natural increase of the current, as observed experimentally (Table 2), influencing the transfer mode of the filler metal which passes from spray (Ar) to globular (CO_2). This is in agreements with Quites (2002) that showed that the shielding gases, according to its nature and composition, have a great influence on the type of transfer of the filler metal. In addition, Modenesi & Nixon (1994) showed too that at lower current densities the transfer mode tends to be globular and in higher densities tend to be spray.

3.2 Tests by scanning electron microscopy (SEM)

Figure 1 shows a micrography where it is seen the root of the welded joint by MIG process with the Argon as shielding gas. Through this figure, it is possible to observe a discontinuity in the root, featuring a incomplete fusion. This defect may explain the lower mechanical strength of this welded joint.

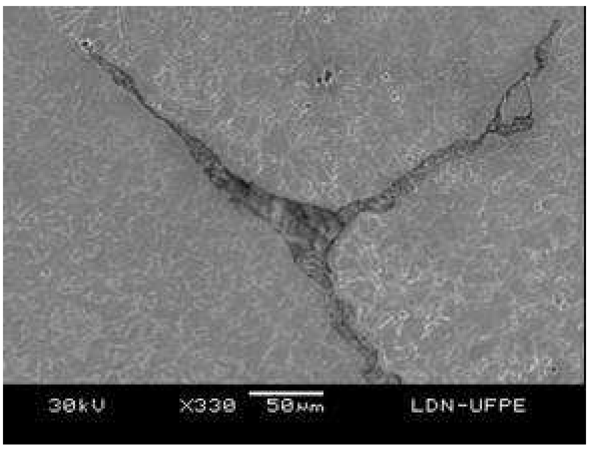

Figure 1 - Micrography of the root of the welded joint with the Ar as shielding gas.

Figures 2-A shows a micrography of the molten metal of the welded joint by MIG process with the Argon as shielding gas and Figure 2-B shows a micrography of the molten metal of the welded joint by MAG process with the CO_2 as shielding gas. Through these figures, it is possible to observe voids on the order of 4μm in both the welded joints. The welded joint with the CO_2 showed a smaller quantity of voids than the welded joint with the Argon, which may explain the greater mechanical strength of the welded joint with the CO_2.

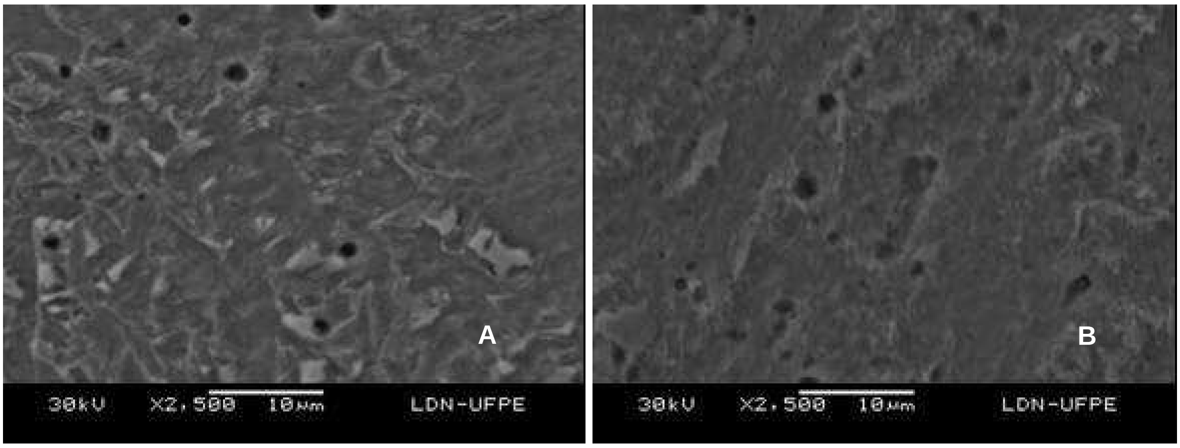

Figure 2 - Micrographs of the molten metals of the welded joints with the Ar (A) and with the CO_2 (B) as shielding gases.

Figures 3-A and 3-B show micrographs of the root and of the molten metal of the welded joint by the MAG process with the mixture (Ar 75% / 25% CO_2) as shielding gas, respectively. Through these figures can be observed that the welded joint processed by the mixture shows no deep voids and their density is lower than the welded joints processed by Ar and by CO_2 as shielding gases. The low density of voids, the lack of deep voids and the complete fusion in the root (Fig. 3-A) may justify the better mechanical behavior for the welded joint in these conditions. Through Figures 3-A and 3-B can be also observed the existence of low relief that may be result of the polishing.

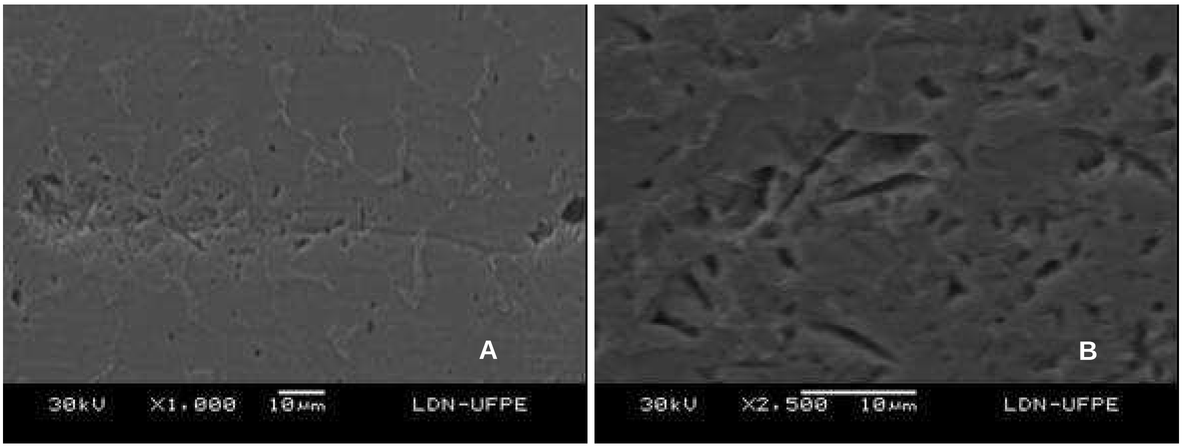

Figure 3 - Micrographs of the root (A) and of the molten metal (B) of the welded joint with the mixture (Ar 75% / 25% CO_2) as shielding gas.

3.3 Tensile Tests

Figure 4-A illustrates the curve Stress (σ) X Strain (%) resulting from the simple arithmetic average of the values of three tests for the welded joint processed by Argon as shielding gas. Observing this figure, it can be observed that the weld presents a low tenacity, having a total strain equal to approximately 12%, and a limit of rupture less than 400MPa. These results can be justified by the existence of a cracking in the root (Figure 1), featuring low penetration, by the high density of voids (Figure 2-A) of the joint welded with the Ar as shielding gas.

Figure 4-B illustrates the curve Stress (σ) X Strain (%) resulting from the simple arithmetic average of the values of three tests for the welded joint processed by the mixture (Ar 75% / 25% CO_2) as shielding gas. In this figure, it was

observed a enough high toughness, with a total strain equal to approximately 28%, and a limit of rupture above 430MPa. These results can be justified by the complete fusion in the root (Figure 3-A), low density of voids, lack of deep voids (Figure 3-B) in the welded joint processed by the mixture (75 Air% / 25% CO_2) as shielding gas.

Figure 4-C illustrates the curve Stress (σ) X Strain (%) resulting from the simple arithmetic average of the values of three tests for the welded joint processed by CO_2 as shielding gas. In this figure, it was observed a high tenacity, with a total strain equal to approximately 24%, and a limit of rupture equal to approximately 420MPa. These results can be justified by the good penetration of the weld and by the intermediate density of voids (Figure 2-B) considering the welded joints processed by the others shielding gases.

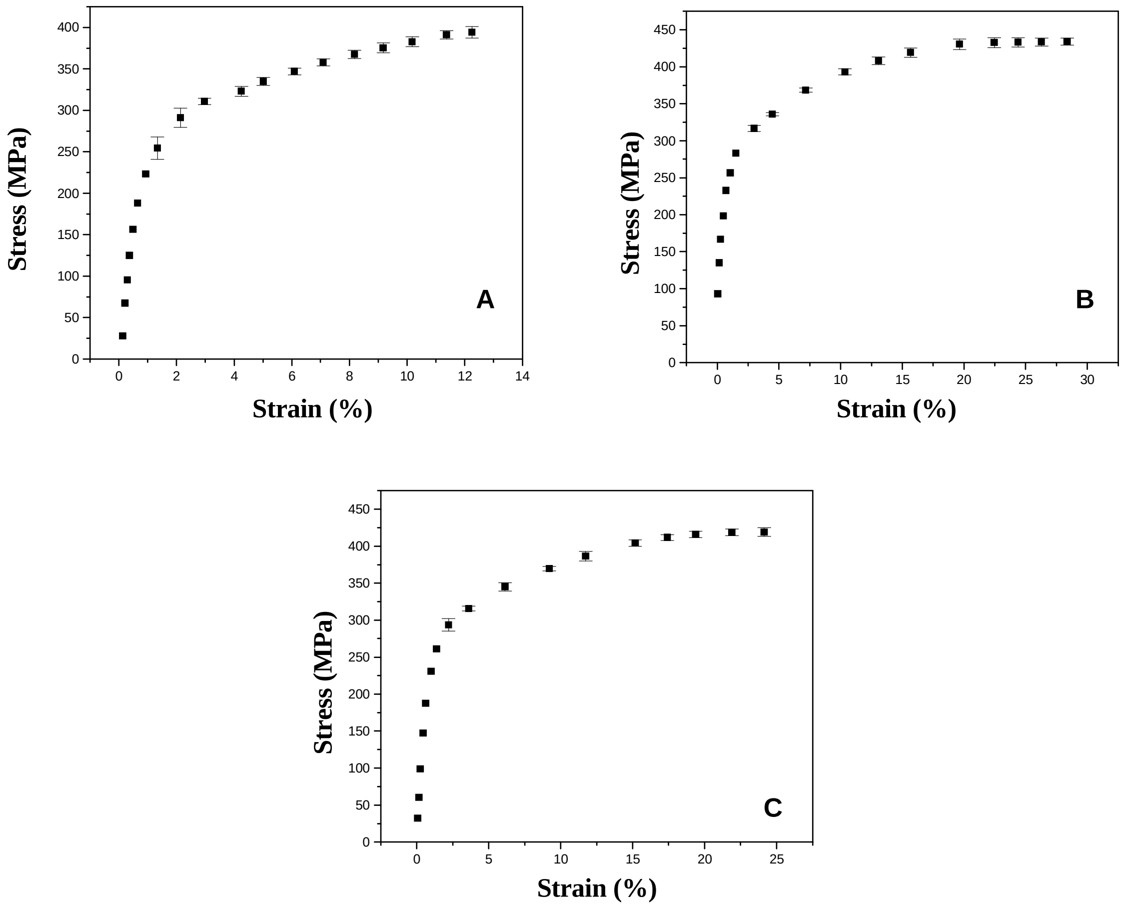

Figure 4 – Curves Stress (σ) X Strain (%) of the welded joints with the Ar (A), the mixture (B) and the CO_2 (C) as shielding gases.

4. CONCLUSION

Transfer mode of the filler metal obtained in the welding carried out with the pure Argon (Ar) and the mixture (Ar 75% / 25% CO_2) as shielding gases was spray (aerosol). Transfer mode obtained in the welding performed with the pure Carbon Dioxide (CO_2) as shielding gas was globular.

The welded joint processed by pure Argon (Ar) presented a failure in the root, characterizing lack of penetration. The welded joints processed by the mixture (Ar 75% / 25% CO_2) or the pure Carbon Dioxide (CO_2) showed no failures in the roots, characterizing good penetration.

The welded joint processed by pure Argon (Ar) showed a high density of voids in the molten metal, which may explain its low toughness and mechanical strength lower that the welded joints with the other shielding gases, as observed in tensile tests.

The welded joint processed by the mixture (Ar 75% / 25% CO_2) showed a low density of voids, lack of depth voids and a complete fusion at the root. The result obtained was a very high toughness and the greater mechanical strength among the three welded joints.

The welded joint processed by pure Carbon Dioxide (CO_2) showed a intermediate density of voids in relation at the welded joints processed by the others shielding gases. The result of toughness and mechanical strength showed that pure CO_2 is a good alternative for GMAW considering the Argon or the mixture cost.

5. REFERENCES

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