THE INFLUENCE OF THE SHIELDING GAS ON THE WELDABILITY OF A FERRITIC STAINLESS STEEL.

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Abstract. *Until not so long time ago the ferritic stainless steel was welded only with austenitcs wires, like AWS ER 308LSi and 307Si, to have a good quality in the weld. Recently, stabilized ferritics stainless wires (for example, the 430Ti, 430LNb e 409Nb), that can give a good quality to the weld of this steels, beyond having a lesser cost. Then, it is necessary to have one study of the influence of the shielding gas on these kind of wires. The objective of this work is to study the influence of some shielding gases compositions (pure argon and oxygen and carbon dioxide mixtures) on the chemical composition and the microestructure of the weld with short circuit transfer mode of the GMAW welding process of the ferritic stainless steel. It was did tests with six shielding gas compositions and the wire ER430, keeping the same medium current and the metal deposited quantity on the ferritic stainless steel plate. The results showed that only exist significant changes on the composition of the carbon. When the oxygen or the carbon dioxide contents increase on the shielding gas generate an increase in the amount of martensite.*

Keywords*: ferritic stainless steel, shielding gas, GMAW, short-circuit.*

1. INTRODUCTION

Ferritics stainless steel are iron-chromium leagues with cubical structures of body centered, predominantly ferritics in any temperature until its fusing. It has between 12 and 30% of chromium and a low carbon content, in general less than 0.1%. The ferritic phase can contain little carbon and nitrogen quantities (interstitial elements) in solution, these is mainly in the form of precipitated (in general, carbide and nitride of chromium) (Kotecki, 1999).

A Fe-17%Cr league, with low carbon and nitrogen contents enough to allow a total ferritic structure, when warm the superior temperatures 1150ºC, will suffer a grain growth, and all carbon and nitrogen will be in solid solution. However, with the cooling, the carbon and nitrogen solubility in the matrix α diminishes, and occurs the chromium carbides and nitrides precipitation, mainly in the grain contours. This intergranular carbides and nitrides precipitation, beyond harming the mechanical properties of ferritics stainless steel, due to loss of the tenacity of the material, becomes these steels susceptible to intergranular corrosion (Pires; Falleiros, 2002).

In high temperatures, above of 1200°C, the ferritic stainless steel tends to present a single-phase structure, completely ferritic. In these conditions, the ferritic structure raised atomic mobility in high temperatures and the particle absence capable to anchor the grain contours make possible a grain growth extremely fast. This growth tends to be lesser in steel stabilized to the niobium or titanium (Modenesi, 2001).

In general the ferritics stainless steel present low weldability (comparative with the austenitic ones), therefore their welds are characterized by low ductility and tenacity beyond sensitivity to the intergranular corrosion. Moreover, the rough grains formation exists. The addition of elements as titanium, copper and aluminum in the welding process carries through a grain refining in the welded metal (Reddy; Mohandas, 2001).

The mechanical properties of a ferritic stainless steel weld are related to the gotten microstructure (presence of a martensite structure), a bad control of this microstructure can limit its application (Balmforth; Lippold, 2000).

In stainless steel MIG/MAG welding the pure argon or mixed with small percentages of oxygen or carbon dioxide is recommended as shielding gas (Lyttle; Stapon, 1990). The Argon (Ar) is an inert gas with low ionization potential, low oxidation potential and low thermal conductivity. In accordance with Dillenbeck; Castagno (1987), the argon high density in comparison with the other gases (1,38 in relation to air) promotes a bigger efficiency of protection, because the argon easily substitutes air around the weld. For being an inert gas the protection to the argon base promotes retention of league elements in the weld fillet, leaving the weld fillet free of inclusions, improving the mechanical properties. Moreover, it facilitates to open the arc, improves the stability in current decreases, beyond allowing spray transferences.

The gas oxygen (O_2) is oxidant that in the mixture with argon alleviates the profile of the fillet weld, improving the quality of the fillet, mainly the wettability of the fusing puddle, for the reduction of the superficial tension in the contact casting puddle/base metal and for the stabilization of the position of the root of the arc (Jönsson et al, 1995). The addition of small amounts of O_2 to the argon (up to 5% of O_2) has influence on the column of the arc reducing the current transition of globular/spray. When the oxygen level increases in the mixture, also increases the losses of league elements, being able to spoil the mechanical properties.

The carbon dioxide (CO_2) is cheapest enters the types of shielding gases and more used in MIG/MAG welding in steel with short circuit transference. The CO_2 dissociation in the arc forms CO and O and the global effect is to generate an oxidant protection (Lyttle; Stapon, 1990). Its high thermal conductivity is responsible for one high heat transference for the base metal a wider standard of penetration and rounded off it is gotten when it is compared with the argon.

Strassburg, (1976) comments that one the ratio increase of oxidants elements in the shielding gas increases the losses of manganese, chromium, niobium. The oxidation losses can be of 0,3% for manganese and chromium and about 0,1% for silicon and niobium, when the text of oxygen in the gas is lesser than 30%.

The carbon dioxide, in the shielding gas, results in carbon inclusions, as well as, an oxidation in the deposited metal. A disadvantage of the carbon inclusions is that the ferrite content in the deposited metal can decrease, because the carbon is strong austenite former (Lundqvist, 1980).

Liao; Chen (1998) had carried through a study evaluating the mechanical properties as well as the microstructures with the change of the shielding gas (pure argon and mixtures of argon with oxygen and/or carbon dioxide) for austenitic stainless steel, where they had observed significant changes, as much in the microstructure, how much in the mechanical properties.

The aim of this work is to study the influence of some shielding gases compositions (pure argon and oxygen and carbon dioxide mixtures) on the chemical composition and the microstructure of the weld with short circuit transfer mode of the GMAW welding process of the wire ER430.

2. EXPERIMENTAL PROCEDURE

For the experimental procedure accomplishment the following equipment had been used: multiprocess welding source; co-ordinated table of with automatic movement of the torch; current and voltage of welding acquisition system, optic emission spectrometer for measurement of the chemical composition, determination system for the microstructures and measurement systems of microhardness.

To compare the influence of the shielding gas in the quality of the weld fillet (in such a way in aspect term, metallurgy and resistance mechanics) it is necessary to find a welding condition that is best possible for all the types of shielding gas. The search of these parameters becomes a little complex in function of the involved amount of variables in the welding process, being necessary to count on some considerations. It is important to always have the same welding current, same deposition rate (to have a constant value enters the wire feeding speed and the welding speed) and if possible to always have the same energy deposited in the weld fillet for all the shielding gases used. It is important also to get always a steady metallic transference for all conditions.

To reach the objective determined in this work, the tests had been divided in two stages: In the first phase it had been carried through tests varying the torch to workpiece distance (of 12 mm to 18 mm). The objective is to determine a value of the average current that can be welded with all the shielding gas types with the short circuit transference. In the first stage of the work it was used ER430 wire-electrode (Table 1) of 1,2 mm diameter, welding on deposition in bi-stabilized ferritic stainless steel plates (Table 2) and the six types of shielding gas (Ar; Ar+2%O_2; Ar+4%O_2; Ar+2%CO_2; Ar+4%CO_2 and Ar+8%CO_2). The welding parameters had been: voltage of 20 V; inductance of ascent and descending of the machine in an average value of the band of variation of the welding source; wire feeding speed of 5,3 m/min and welding speed of 20 cm/min. The used welding parameters had been based on preliminary tests where the characteristics of the weld fillet and the oscillograms of voltage and current of welding had been observed. Four experiments for each condition had been become fullfilled so that if it could get a bigger trustworthiness in the gotten results.

Table 1. Chemical composition of the ER430 wire electrode

Elem.	**C**	**Cr**	**Mn**	**S**	**P**	**Si**	**Ti**
Val.	0,0755	16,5	0,308	0,0113	0,025	0,43	0,0024

Table 2. Chemical composition of the ferritic stainless steel used

Elem.	**C**	**Cr**	**Mn**	**N**	**Nb**	**Ni**	**P**	**S**	**Si**	**V**	**Ti**
Val.	0,0095	17,1284	0,1434	0,0075	0,2009	0,1777	0,0234	0,0027	0,4032	0,0507	0,1984

For the second stage they had been manufactured, using the parameters found in the previous stage, test specimens with three deposited bead on plate layers, where if it carried through the measurements of chemical composition and microhardness, beyond verification of the microstructure gotten for the ER430 and the six types shielding gases using the gotten parameters of welding in the first stage. Figure 1 shows as the test specimens had been manufactured. The objective of this phase is to compare the gotten properties using the same conditions of welding.

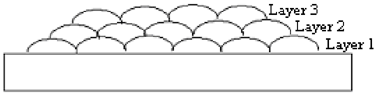


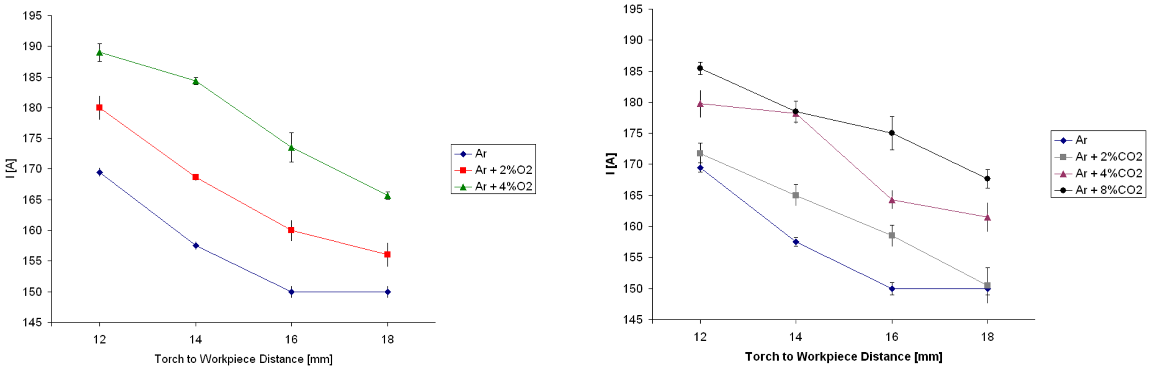
Figure 1. Format of the test specimens

The chemical analysis was carried through by optic emission spectrometer in the third weld layer, having been the 40x40 mm dimension of test specimens, the microstructure and the microhardness had been verified in the last fillet of the last weld layer. Being that the microhardness was carried through of random form, enclosing three measures in the ferritic matrix of the material and three measures in the martensite.

3. RESULTS AND DISCUSSION

3.1. Torch to Workpiece Distance Variation

In this stage tests varying of torch to workpiece distance had been become fullfilled to find the same energy of welding for the six shielding gases used. Figure 2 shows the tests carried through for the torch to workpiece distance variation, where in the part (a) it represents the variations carried through for the shielding gas with oxygen mixtures and the part (b) presents the variations with mixtures of carbon dioxide. The lines binding the points had been placed to assist in the understanding of the trends.



(a) (b)

Figure 2. Influence of the gap in the chain for argon and mixtures of argon with: (a) oxygen; (b) carbon dioxide

Analyzing the trend of the curves of Figure 2 to observe itself that a reduction in the current of welding with the increase of the torch to workpiece distance occurs. Carrying through an analysis with the aid of the consumption formula it can be observed that for an increase of the torch to workpiece distance it will have an increase of the length of the stickout, that it causes a bigger heating of the electrode before occurring to the fusing (effect joule), diminishing with this the welding current for the source with constant voltage static characteristic. An increase in the length of the arc also occurs, that also will generate a reduction of the value of the average chain. It is important to also detach that the increase of the torch to workpiece distance affects the profile of the electric arc.

With regard to the influence of the protection gas, it can be observed in Figure 2 that it had a trend in such a way to increase the current with the increase of the O_2 how much in CO_2 contained in the mixtures with Ar. This increase is consequently must probably the changes in the arc format (alteration in the length and width of the arc) and in the voltage for source with constant voltage static characteristic. Hilton; Norrish, (1988) comments that the addition of CO_2 or O_2 to Ar diminishes the nucleus of the arc conduction (had mainly to the increase of the thermal conductivity) and depending on the amount of these gases in the arc they can harm or same to improve the stability of the arc.

With the results presented in Figure 1, it is possible to choose a welding condition that is same for all the used gases, keeping the same energy of welding generated in the arc. With this it is possible to make to the comparative analysis of the influence of the shielding gas in the weld fillet. The chosen condition was a torch to workpiece distance of 12 mm and an average current of 170. In such a way was obtained to arrive the parameters presented in Table 3.

To prove that the welding used the same energy generated in the arc, one measured the profiles of weld fillet was done. Analyzing Figure 3 it is noticed that it independently did not have a significant variation in the profiles (width, penetration and reinforcement) of the used shielding gas, proving that the energy was practically same for all the tests, making possible the comparative study enters the shielding gases.

Table 3 Conditions of standardized welding in the work

Gas	**Flow [L/min]**	**U [V]**	**$V_{FEEDING}$ [m/min]**	**V_{WELD} [cm/min]**	**GAP [mm]**	**I [A]**
Ar	14	20	5,3	20	12	172
Ar + 2% O_2	14	20	5,3	20	15	173
Ar + 4% O_2	14	20	5,3	20	17	171
Ar + 2% CO_2	14	20	5,3	20	14	172
Ar + 4% CO_2	14	20	5,3	20	15	174
Ar + 8% CO_2	14	20	5,3	20	16	172

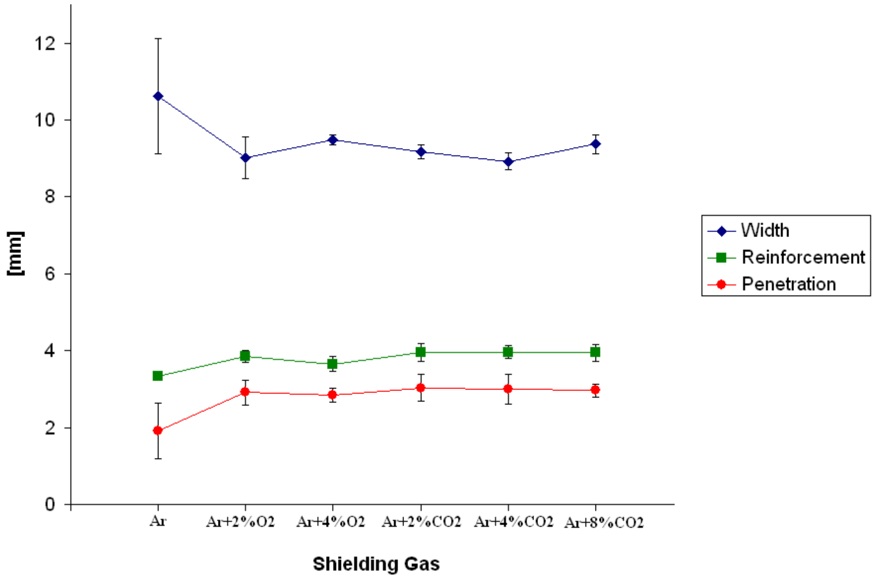


Figure 3. Carried through geometric measurements in weld fillet

3.2. Analysis of the Chemical Composition of the Weld Third Layer

It enters the elements analyzed during the work was observed that the ones that had shown significant changes had been the carbon, the chromium, the manganese and the silicon, as can be observed in Table 4. Figure 4 shows the variation of the carbon percentage in the weld metal in function of the used shielding gas. One notices that with the increase of the text of oxygen in the mixture with argon it does not cause significant changes. To step that when it was used the carbon dioxide had an addition of 0,027% of carbon, considering 8%CO_2. The reason of the carbon increase in the weld fillet is because the carbon of the shielding gas chemical composition. This fact also was observed by Liao; Chen (1998) when analyzing the influence of the shielding gas in austenitic stainless steel.

Table 4. Chemical compositions for ER430 wire

Elem.	BM	ER430	3CT	Ar	Ar+2%O_2	Ar+4%O_2	Ar+2%CO_2	Ar+4%CO_2	Ar+8%CO_2
C	0,0095	0,0755	0,074	0,0785	0,0809	0,0811	0,0904	0,0904	0,1043
Co	-	-	-	0,0165	0,0169	0,0174	0,0173	0,0173	0,0172
Cr	17,1284	16,5	16,51	16,207	16,204	16,158	16,22	16,22	16,192
Cu	-	-	0,0	0,0367	0,0364	0,0352	0,0378	0,0378	0,0368
Mn	0,1434	0,308	0,3	0,2552	0,246	0,229	0,2515	0,2515	0,2325
Mo	-	-	0,0	0,0668	0,0671	0,0666	0,0668	0,0668	0,0662
N	0,0075	-	-	-	-	-	-	-	-
Nb	0,2009	-	0,0	0,0157	0,0159	0,0167	0,016	0,016	0,018
Ni	0,1777	-	0,0	0,208	0,207	0,207	0,21	0,21	0,208
P	0,0234	0,025	-	0,0199	0,0201	0,0199	0,02	0,02	0,0203
S	0,0027	0,0113	-	0,0095	0,01	0,0097	0,0095	0,0095	0,0096
Si	0,4032	0,43	0,43	0,411	0,4163	0,3878	0,4209	0,4209	0,3954
Sn	-	-	-	0,0066	0,0068	0,0066	0,007	0,007	0,0068
Ti	0,1984	0,0024	-	0,0083	0,0085	0,0087	0,009	0,009	0,0079
V	0,0507	-	-	0,099	0,0976	0,0979	0,0988	0,0988	0,0969
W	-	-	-	0,1471	0,1467	0,1477	0,1472	0,1472	0,1451

Where BM is base metal and 3CT is the chemical composition of the last layer.

Figure 5 presents the variation of the chromium composition with the composition of the shielding gas. It is verified that a reduction of the chromium content (approximately 0.3%) not depend of the shielding gas type used, comparing with the chromium content in the wire. This fact if must probably the chromium oxide formation in the surface of the fillet. This fact also was observed by Liao; Chen (1998).

Figures 6 and 7 respectively present the chemical composition variation of manganese and silicon with the shielding gas composition variation. It is verified that the increase in such a way of the carbon dioxide as oxygen they generate a reduction in the presence of those elements in the weld fillet. A reduction of the content of these elements compared with the content found in the wire is also observed. These facts is must probably the oxide formation. The manganese and the silicon are elements also used with deoxidizing in the fusing puddle.

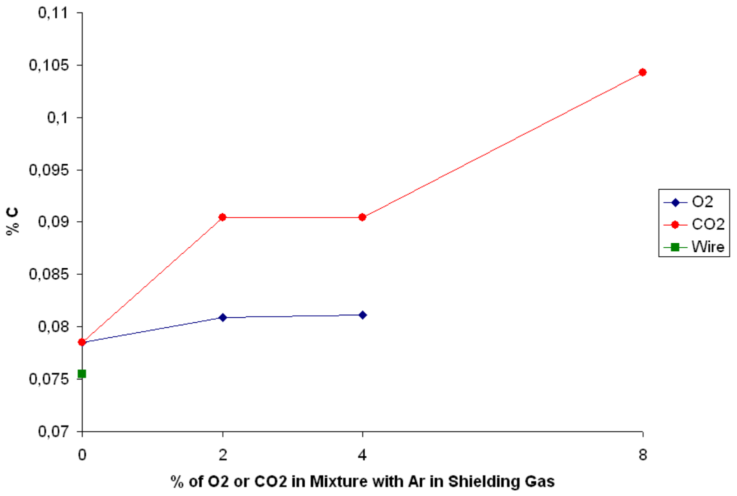


Figure 4. Carbon percentage in the weld metal

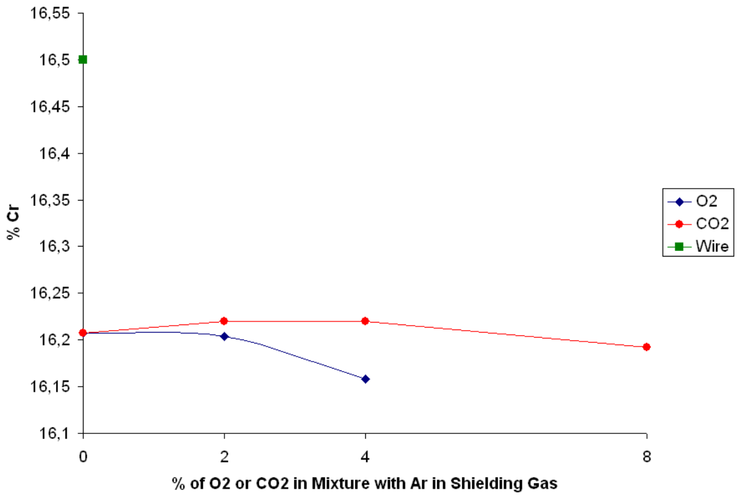


Figure 5. Chromium percentage in the weld metal

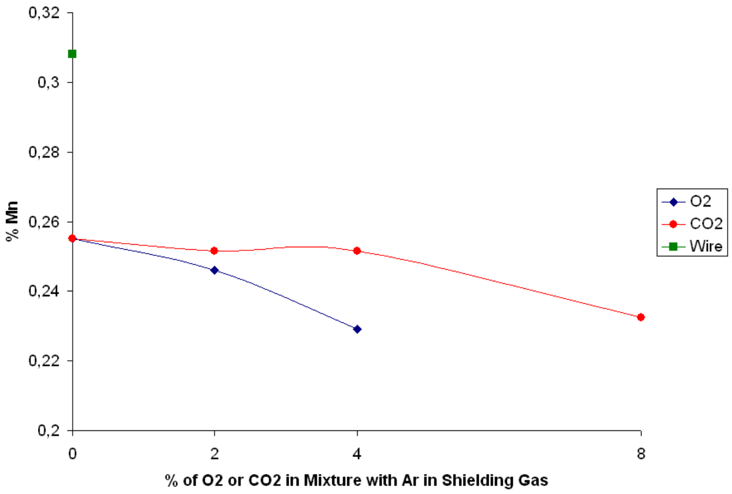


Figure 6. Manganese percentage in the weld metal

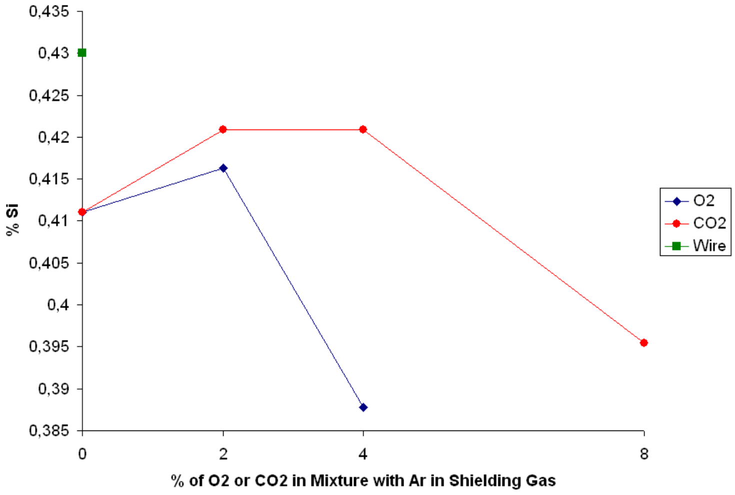


Figure 7. Silicon percentage in the weld metal

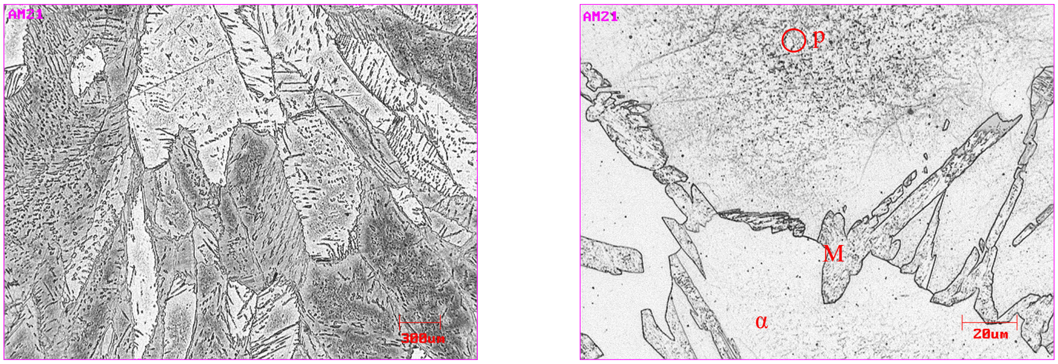
3.3. Microestrutural Analysis of the Weld Third Layer

The Figures 8 to 13 respectively present the microstructure of the casting zone (center of the fillet) of the test specimens for ER430 electrode and the shielding gases Ar, Ar+2%O_2, Ar+4%O_2, Ar+2%CO_2, Ar+4%CO_2 and Ar+8%CO_2. The images had been carried through by optic microscopy where (a) possess an increase of 25X and (b) an increase of 500X. In the Figures α represents the ferritic matrix, M represents martensite and P the precipitateds.

Analyzing Figures 8 to 13 columnar structures are observed, being a ferritic matrix with precipitations of martensite in the contours of grains. The presence is also observed of precipitated, with bigger concentration in the grain interior. This fact is more evident in the Figure 8 (b).

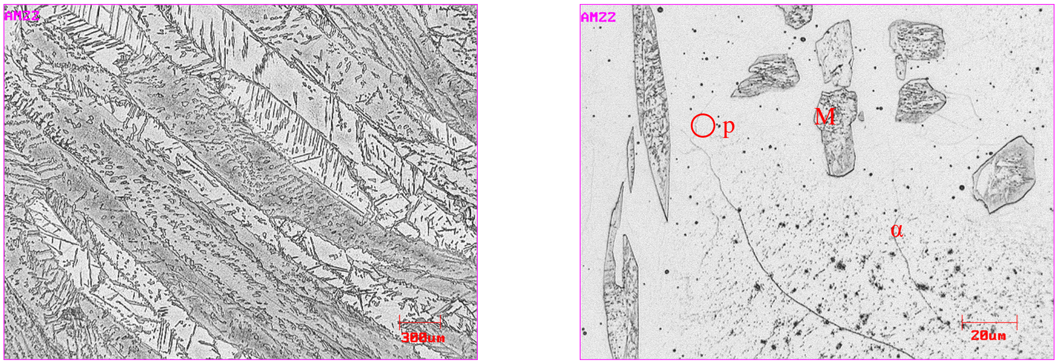
With the increase of the oxygen content with argon mixtures it is not possible to observe with clarity change in the amount of precipitated, as well as in the amount of martensite formed. Future works could be carried through with the objective to study with more clarity the effect of the oxygen in the amount of precipitated and martensite in the weld fillet.

With the increase of the carbon dioxide content is perceived that an increase in the amount of martensite of contour of grains occurs, can also be proven by the increase of the carbon text in the weld fillet. Modenesi (2001) quotation that the presence of α structures stabilizer elements, particularly the carbon expands the field of existence of the austenite for bigger chromium contents, being able with this to suffer transformation from ferrite in austenite, that in the cooling can transform into martensite. How much to the amount of precipitated it is not possible to observe without a deeper analysis.



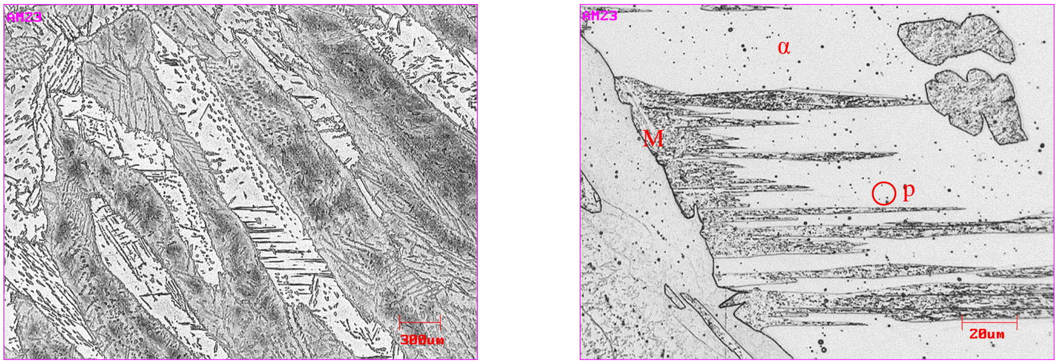
(a) (b)

Figure 8. Casting zone microstructure of ER430 electrode and shielding gas Ar



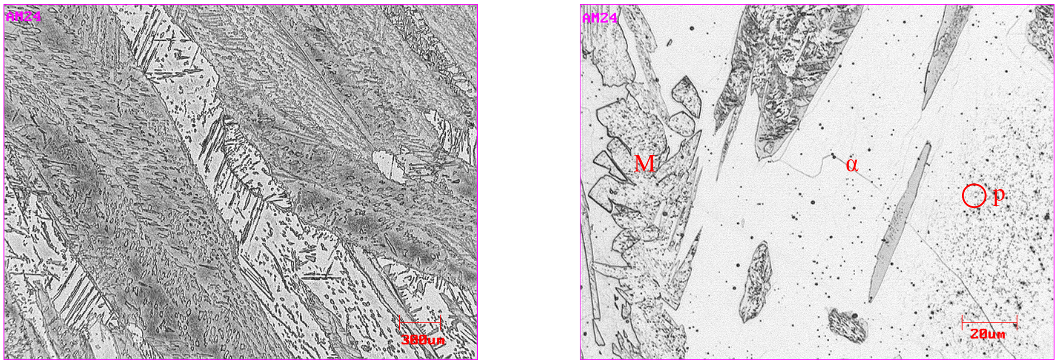
(a) (b)

Figure 9. Casting zone microstructure of ER430 electrode and shielding gas Ar +2%O2.



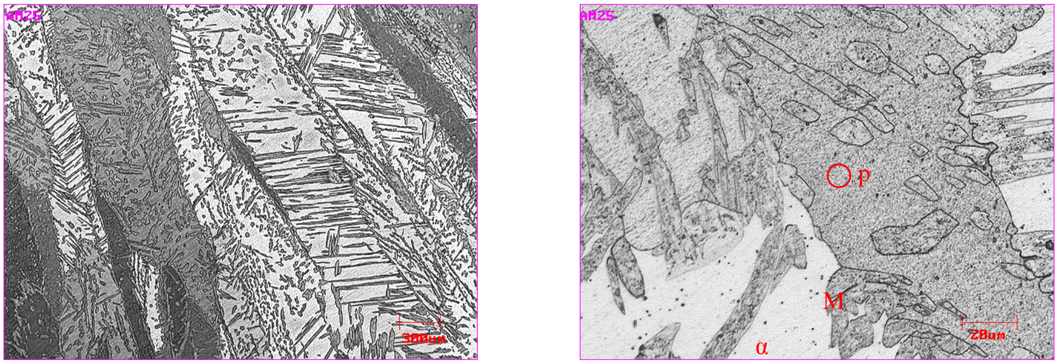
(a) (b)

Figure 10. Casting zone microstructure of ER430 electrode and shielding gas Ar +4%O2.



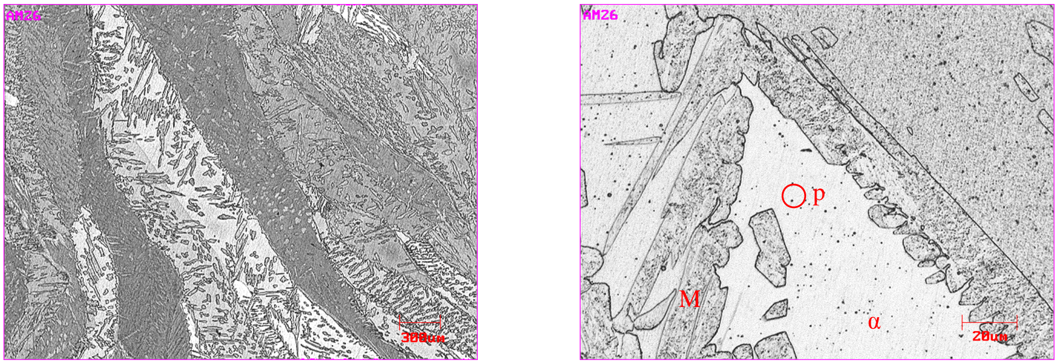
(a) (b)

Figure 11. Casting zone microstructure of ER430 electrode and shielding gas Ar +2%CO2.



(a) (b)

Figure 12. Casting zone microstructure of ER430 electrode and shielding gas Ar +4%CO2.



(a) (b)

Figure 13. Casting zone microstructure of ER430 electrode and shielding gas Ar +8%CO2.

3.3. Microhardness Analysis of the Weld Third Layer

Figure 14 presents the measures of Vickers's microhardness carried through in the ferritic matrix in function of the shielding gas used for the test specimens. One notices that it did not have a significant variation in the microhardness measures in the matrix of the test specimens.

Figure 15 presents the measures of Vickers's microhardness carried through in the martensite in function of the shielding gas used for the test specimens. One notices that it did not have a significant variation in the microhardness measures found in the martensite.

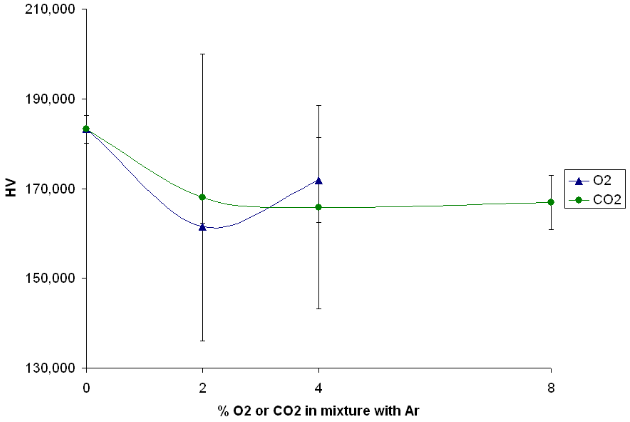


Figure 14. Graph of the microhardness measures in the matrix

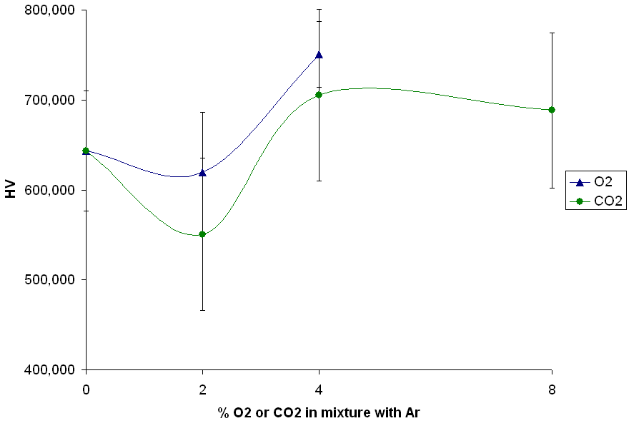


Figure 15. Graph of the microhardness measures in the martensite

4. CONCLUSIONS

With the conditions of assays carried through in this work, it can conclude the following one:

- It is possible to weld with all the shielding gases with one same welding energy;
- With the increase of the carbon dioxide content in the mixture with argon it has an increase in the amount of carbon contained in the weld;
- Exist one reduction of the chromium content independently of the shielding gas used comparing with the chromium text in the wire;
- It is verified that the increase in such a way of the carbon dioxide as of the oxygen they generate a reduction in the presence of manganese and silicon in the weld fillet;
- Columnar grains were observed, being a ferritic matrix with precipitations of martensite in the contours of grains for all the shielding gases;
- With the increase of the carbon dioxide content one perceives that an increase in the amount of martensite of contour of grains occurs;
- It independently does not have significant changes in the microhardness measured in the ferritic matrix of the shielding gas used, the same happens in the measurements in the martensite.

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