THE INFLUENCE OF SHIELDING GASES WITH HIGH PERCENTAGE OF CO_2 ON THE MICROSTRUCTURE OF FERRITIC STAINLESS STEEL WELDS

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Abstract. Ferritic stainless steels are not characterized by good weldability. Wires made of austenitic stainless steels are usually applied to join ferritic materials because of the good mechanical resistance, tenacity and ductility reached by austenitic weld metal. However, noval ferritic stainless steel wires, stabilized with Nb and Ti, have been developed to tackle the target of matching the required mechanical properties and keeping the costs lower by using ferritic stainless steels. These ferritics wires are been used in the exhaust systems manufacturing using shielding gases with high percentage of CO_2 and there aren't studies to show what can happen in the microstructure. The aim of this work was to study the influence of the shielding gas composition (pure argon and mixtures with O_2 or CO_2) on the microstructure of weld deposits obtained with GMAW using stabilized ferritic wires (ER430Ti and ER430LNb) in ferritic base metal (UNS 43932 and AISI 441) used in the exhaust system industries. The study was made comparatively to an austenitic wire (ER308LSi). A special experimental approach was applied to permit more reliable comparison amongst different combinations wire-shielding gas. The results showed that the shielding gas composition doesn't play important role on the final microstructure of the deposits, but to one wire it was showed that the grain was increase.

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

1. INTRODUCTION

The market for stainless steels has experienced constant growth because of the above mentioned excellent material properties and continuous manufacturing improvement, especially when items like process productivity increase and cost reduction are taken in consideration. Recently, producers have faced a sharp increase in the international prices of the alloying elements, mainly, nickel and molybdenum. As a result, the most traditional class (austenitic) went through severe price raise worldwide. An alternative for some applications is the use of ferritic stainless steel, containing no nickel.

Ferritic stainless steels are widely used in automotive exhaust system parts because they possess excellent corrosion resistance and high temperature properties. They are more economical than the austenitic stainless steels, which contain large amounts of expensive Ni, and have small thermal expansion coefficients.

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). Balmforth; Lippold (2000) cited that 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.

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). But now ones there are some companies that are using large quantities of carbon dioxide in mixture with argon, and there aren't studies to know what happened in the weld if these kind of shielding gases.

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.

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.

Notwithstanding, the volume of information available in the literature on GMAW welding with ferritic stainless steel wire is still very scarce, mainly in relation to shielding gases, specially because of the recent use of large quantities of carbon dioxide in mixture with argon. Thus, this paper seeks to analyze the metallurgical characteristic of ferritic stainless steel welding by studying the influence of the shielding gas compositions (argon and mixtures with O_2 or CO_2) on the microstructure of the weld bead of ferritic stainless steels.

2. EXPERIMENTAL PROCEDURE

For the experimental procedure accomplishment the following equipments had been used: multiprocess welding source; co-ordinated table with automatic movement of the torch; current and voltage of welding acquisition system and determination system for the microstructures.

Three different types of wires for GMAW (AWS classes ER308LSi, ER430Ti and ER430LNb, all of them with 1.0 mm) were used to study the influence of stabilizers on the deposit microstructure. The ER308LSi were used (as reference) because it is the most used in the industry. Each wire was combined with different shielding gas to depict the influence of the arc environment of the microstructure of the fusion zone. The chemical composition of the wires can be seen in the Table 1.

Table 1. Chemical composition measured of the wires (weight, %)

Elem.	C	N	Cr	Mn	Nb	Ni	S	Si	Ti
ER308LSi	0,018	0,056	19,620	1,930	0,001	10,290	0,012	0,750	0,056
ER430Ti	0,108	0,014	17,450	0,650	0,001	0,400	0,002	1,040	0,350
ER430LNb	0,027	0,014	17,660	0,425	0,440	0,440	0,004	0,430	0,004

2-mm-thick test plates with 50 x 300 mm were used as base metal. They were made of two kinds of bi-stabilized ferritic stainless steel (UNS43932 and AWS 441). The chemical composition of the base metals can be seen in the Table 2.

Table 2. Chemical composition measured of the wires (weight, %)

MB	Cr	C	N	Ti	S	Nb	ΔTi	ΔNb
43932	17,05	0,011	0,013	0,2	0,0015	0,19	0,14	0,14
441	18,01	0,014	0,009	0,13	0,0012	0,56	0,08	0,49

It was used only Ar+2%O_2 as shielding gas to the ER308LSi, because this is the combination that is the most used in the in industry, than this condition was used as reference. For the others wires it was used five kinds of shielding gas, Ar, Ar+2%O_2, Ar+4%CO_2, Ar+8%CO_2 and Ar+25%CO_2. The last one it was used because some companies are welding ferritic stainless steel with that kind of shielding gas, but it doesn't have studies to know what happened in the microstructure and properties of the weld.

To compare the influence of the shielding gas in the quality of the weld bead 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 as 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 find the weld conditions to all the combinations, that give a similar energy, tests had been done varying the contact tip-to-work distance (CTWD), and keeping the others parameters constant. It was used a voltage of 16 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 4 m/min and welding speed of 20 cm/min, in butt joints as can be seen in the Figure 2. The aim was to have to all the conditions one current of 90 A. Microstructural analysis on the fusion zone were done.

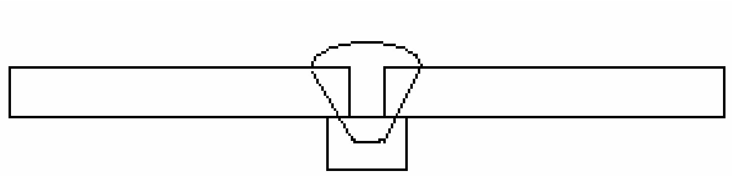

Figure 1. Format of the test specimens

The Tables 3 to 5 present the weld conditions to the wires ER308LSi, ER430Ti and ER430LNb respectively. It is important to emphasize that to all the conditions of this work the current used was almost 90 A, as can be seen in these three Tables.

Table 3. Welding condition to ER308LSi

Shielding Gas	**CTWD [mm]**	**$V_{FEEDING}$ [m/min]**	**V_{WELD} [cm/min]**	**U [V]**	**I [A]**
$Ar+2\%O_2$	14	4	20	16	92

Table 4. Welding condition to ER430Ti

Shielding Gas	**CTWD [mm]**	**$V_{FEEDING}$ [m/min]**	**V_{WELD} [cm/min]**	**U [V]**	**I [A]**
Ar	16	4	20	16	90
$Ar+2\%O_2$	17	4	20	16	90
$Ar+4\%O_2$	16	4	20	16	89
$Ar+8\%CO_2$	14	4	20	16	89
$Ar+25\%CO_2$	14	4	20	16	89

Table 5. Welding condition to ER430LNb

Shielding Gas	**CTWD [mm]**	**$V_{FEEDING}$ [m/min]**	**V_{WELD} [cm/min]**	**U [V]**	**I [A]**
Ar	16	4	20	16	90
$Ar+2\%O_2$	20	4	20	16	92
$Ar+4\%O_2$	20	4	20	16	89
$Ar+8\%CO_2$	21	4	20	16	92
$Ar+25\%CO_2$	22	4	20	16	91

3. RESULTS AND DISCUSSION

3.1. Weld Bead Aspect

The Figures 2 to 6 present the aspects for all the conditions that can be seen in the Tables 3 to 5. With these Figures is possible to see that we had almost the same energy for all the conditions, because the weld beads had almost the same dimensions. It is important to see that for all the conditions there were almost nothing of oxide in the weld bead, it is probably because of the wire and base metal stabilization.

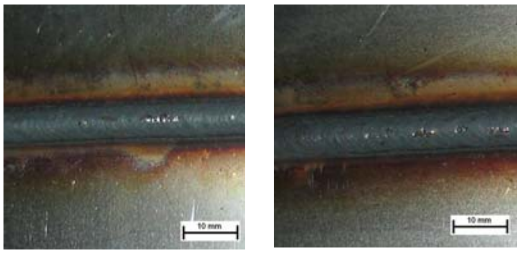

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Figure 2. Weld bead aspect welded with ER308LSi and $Ar+2\%O_2$ to the base metal: a-439 and b-441

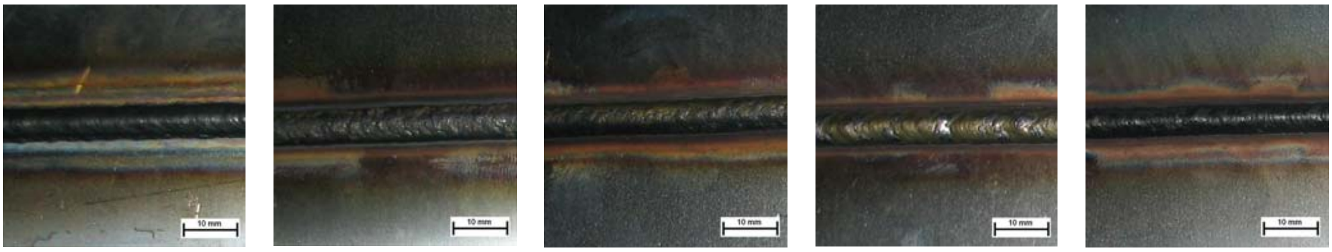

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Figure 3. Weld bead aspect welded with ER430Ti, base metal 439 and shielding gas: a-Ar, b-$Ar+2\%O_2$, c-$Ar+4\%CO_2$, d-$Ar+8\%CO_2$ and e-$Ar+25\%CO_2$

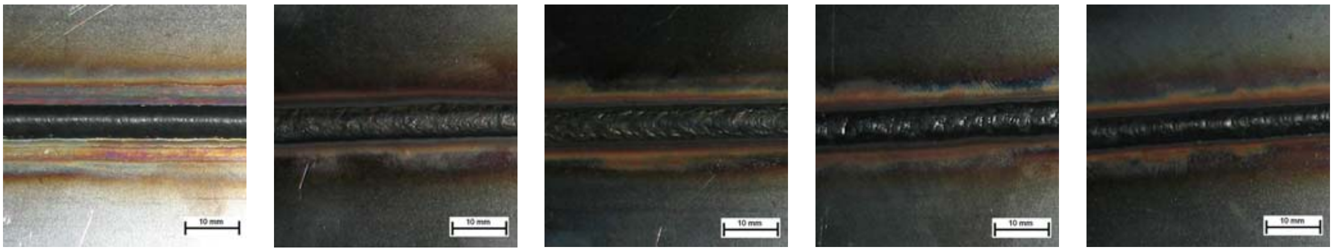

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Figure 4. Weld bead aspect welded with ER430Ti, base metal 441 and shielding gas: a-Ar, b-$Ar+2\%O_2$, c-$Ar+4\%CO_2$, d-$Ar+8\%CO_2$ and e-$Ar+25\%CO_2$

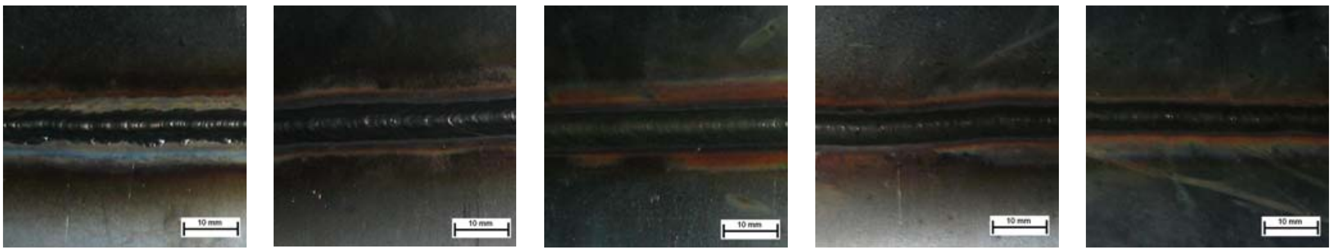

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Figure 5. Weld bead aspect welded with ER430LNb, base metal 439 and shielding gas: a-Ar, b-$Ar+2\%O_2$, c-$Ar+4\%CO_2$, d-$Ar+8\%CO_2$ and e-$Ar+25\%CO_2$

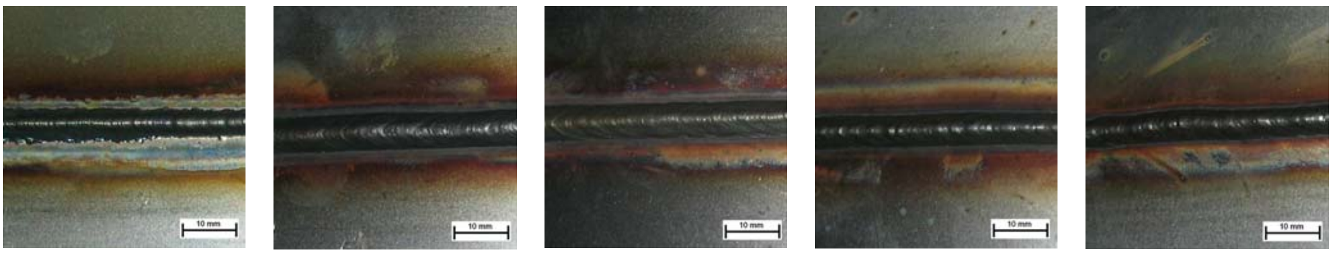

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Figure 6. Weld bead aspect welded with ER430LNb, base metal 441 and shielding gas: a-Ar, b-$Ar+2\%O_2$, c-$Ar+4\%CO_2$, d-$Ar+8\%CO_2$ and e-$Ar+25\%CO_2$

3.2. Microestrutural Analysis

The Figures 7 and 8 present the microstructure of the fusion zone (center of the bead) for the bead welded with ER308LSi and the shielding gas Ar+2%O_2, to 439 and 441 respectively. The images had been carried through by optic microscopy where (a) possess an increase of 10x and (b) an increase of 45x. It can be seen an austenitic matrix with small grains.

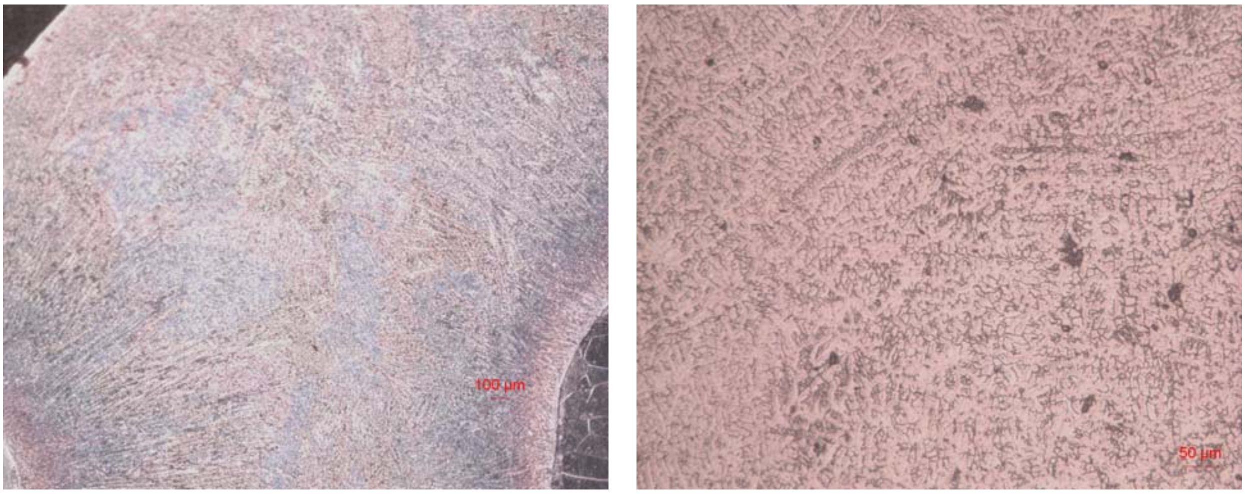

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Figure 7. Microstructure of the fusion zone of the 439 welded with ER308LSi and Ar+2%O_2

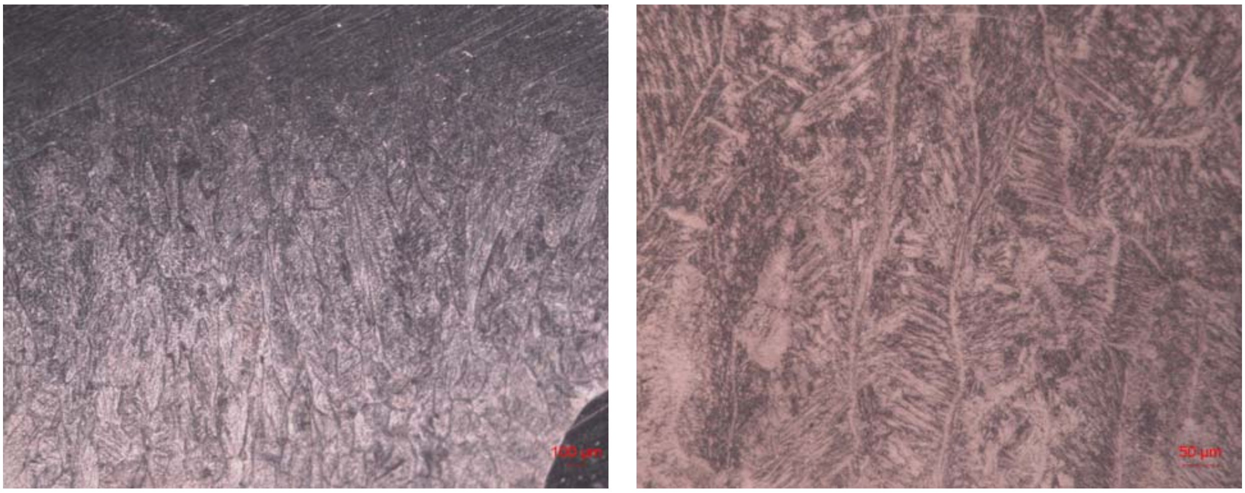

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Figure 8. Microstructure of the fusion zone of the 441 welded with ER308LSi and Ar+2%O_2

The Figures 9 and 11 present the microstructure of the fusion zone (center of the bead) for the bead welded with ER430Ti and the shielding gas Ar, to 439 and 441 respectively. The Figures 10 and 12 present the microstructure of the fusion zone (center of the bead) for the bead welded with ER430Ti and the shielding gas Ar+25%CO_2, to 439 and 441 respectively. The images had been carried through by optic microscopy where (a) possess an increase of 10x and (b) an increase of 45x. It can be seen an austenitic matrix with small grains.

To the both base metals, using all the five shielding gases used, as can be seen in the Figures 9 to 12 all the microstructure was composed by a ferritic matrix. At least with the shielding gas Ar+25%CO_2 there wasn't any formation of martensite, it can be explained by the stabilization of the wire and the base metal.

To achieve steel stabilization it is necessary to add a correct amount of stabilizing elements. A short amount of them allows formation of Cr precipitates (corrosion related problems). Stabilizers in excess worsen the mechanical properties of the joint (intermetallic compound precipitation). DeArdo et al (1996) proposed Equations 1 and 2 to estimate the appropriate amount of Ti and Nb in ferritic stainless steel based metal, according to the interstitial element (C + N) contents.

$$\Delta Ti = Ti - 4\,C - 3{,}42\,N \text{ (for steels stabilized with Ti)} \qquad (1)$$

$\Delta Nb = Nb - 7{,}74\,(C + N)$ (for steels stabilized with Nb) (2)

The worse stabilization of the ER430Ti can be seen by the increase of the grain size with the dioxide carbon content.

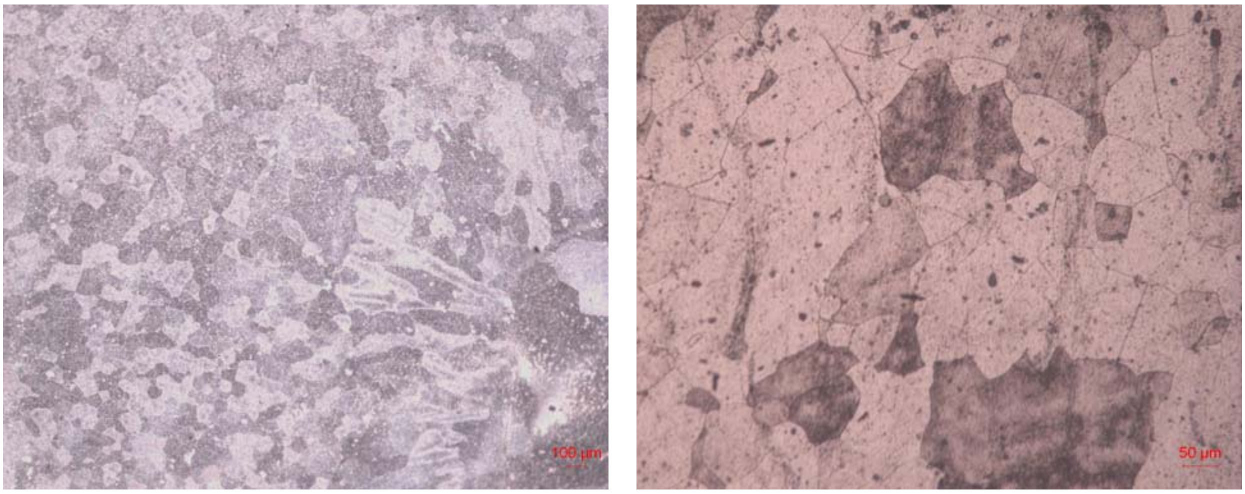

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Figure 9. Microstructure of the fusion zone of the 439 welded with ER430Ti and Ar

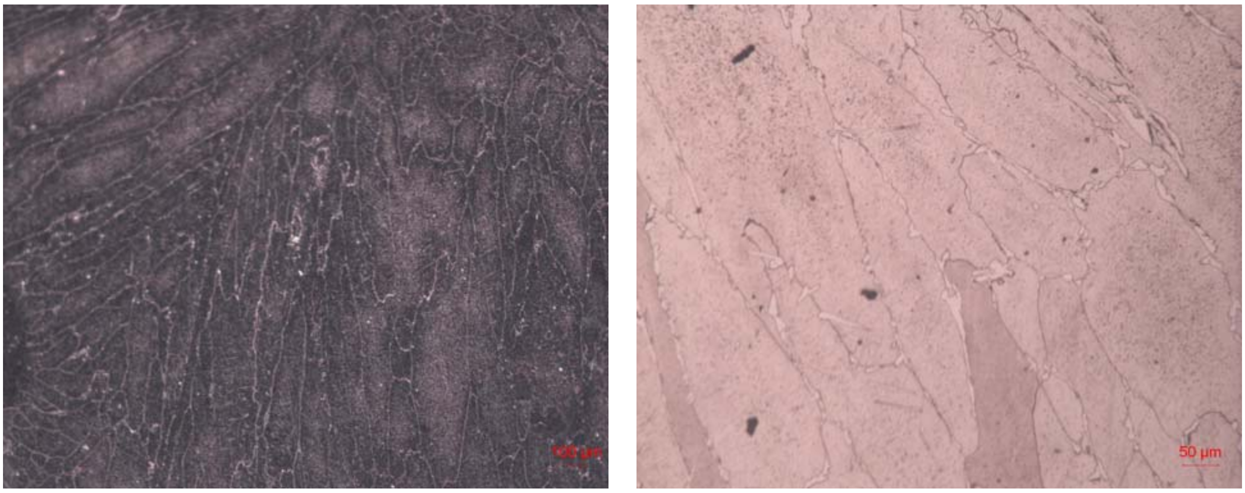

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Figure 10. Microstructure of the fusion zone of the 439 welded with ER430Ti and Ar+25%CO_2

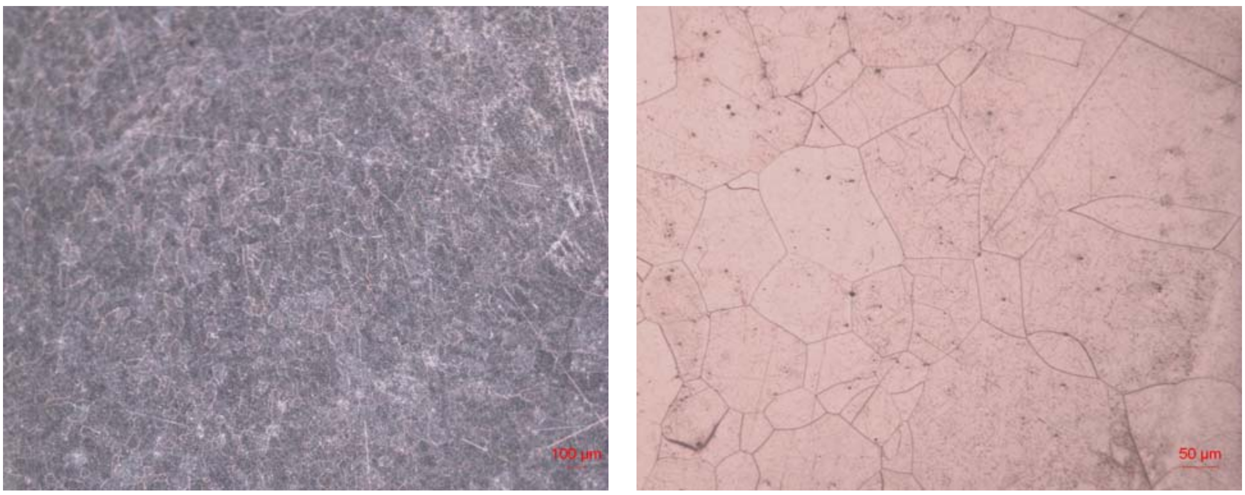

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Figure 11. Microstructure of the fusion zone of the 441 welded with ER430Ti and Ar

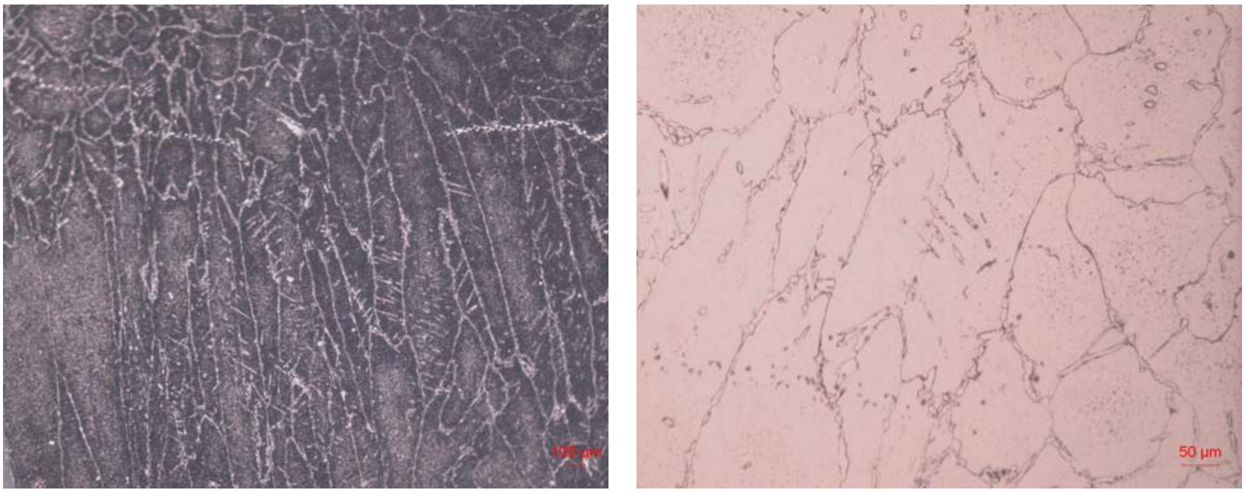

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Figure 12. Microstructure of the fusion zone of the 441 welded with ER430Ti and Ar+25%CO_2

The Figures 13 and 15 present the microstructure of the fusion zone (center of the bead) for the bead welded with ER430LNb and the shielding gas Ar, to 439 and 441 respectively. The Figures 14 and 16 present the microstructure of the fusion zone (center of the bead) for the bead welded with ER430LNb and the shielding gas Ar+25%CO_2, to 439 and 441 respectively.The images had been carried through by optic microscopy where (a) possess an increase of 10x and (b) an increase of 45x. It can be seen an austenitic matrix with small grains.

In the same way of the ER430Ti, to the both base metals, using all the shielding gases, as can be seen in the Figures 13 to 16 all the microstructure was composed by a ferritic matrix. And with all the shielding gases, including the Ar+25%CO_2, there wasn't any formation of martensite, it can be explained by the stabilization of the wire and the base metal.

In comparison with ER430Ti, the fusion zone are formed by coarse grains, it can be related with the dissociation of the Nb precipitations, that starts in low temperatures, than it can be happened an increase of the ground boundary.

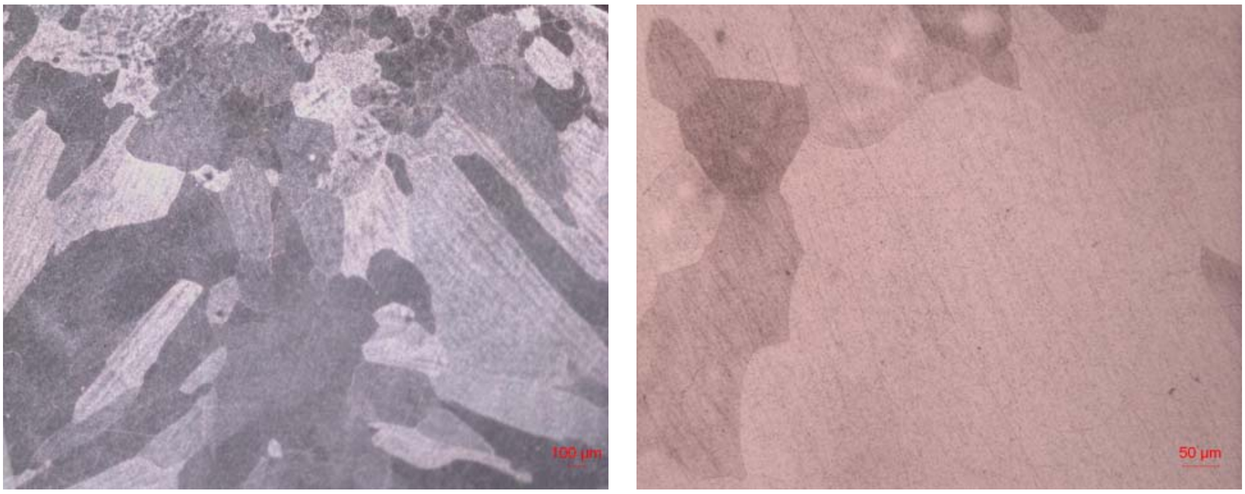

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Figure 13. Microstructure of the fusion zone of the 439 welded with ER430LNb and Ar

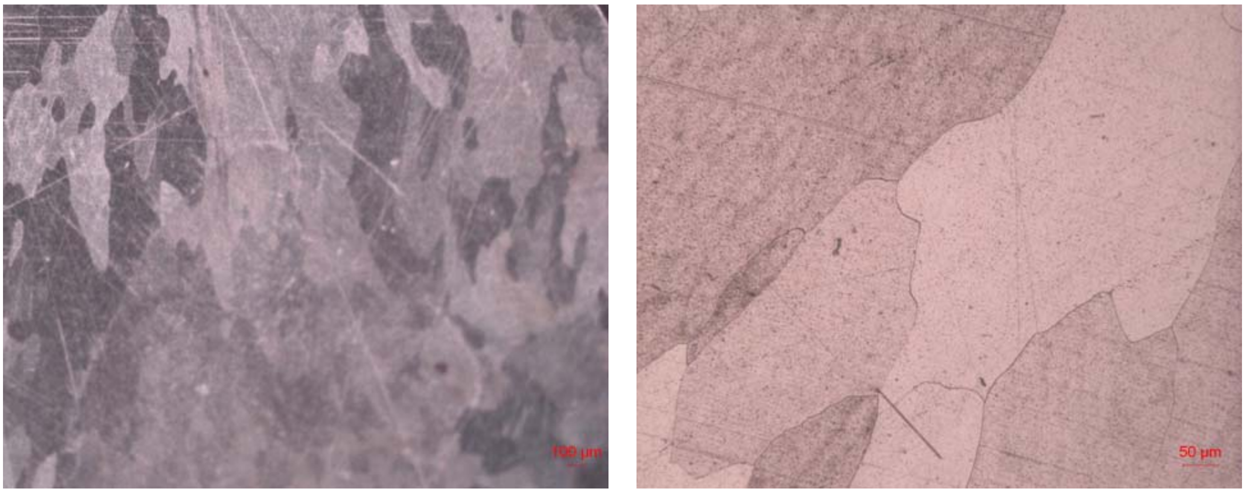

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Figure 14. Microstructure of the fusion zone of the 439 welded with ER430LNb and Ar+25%CO_2

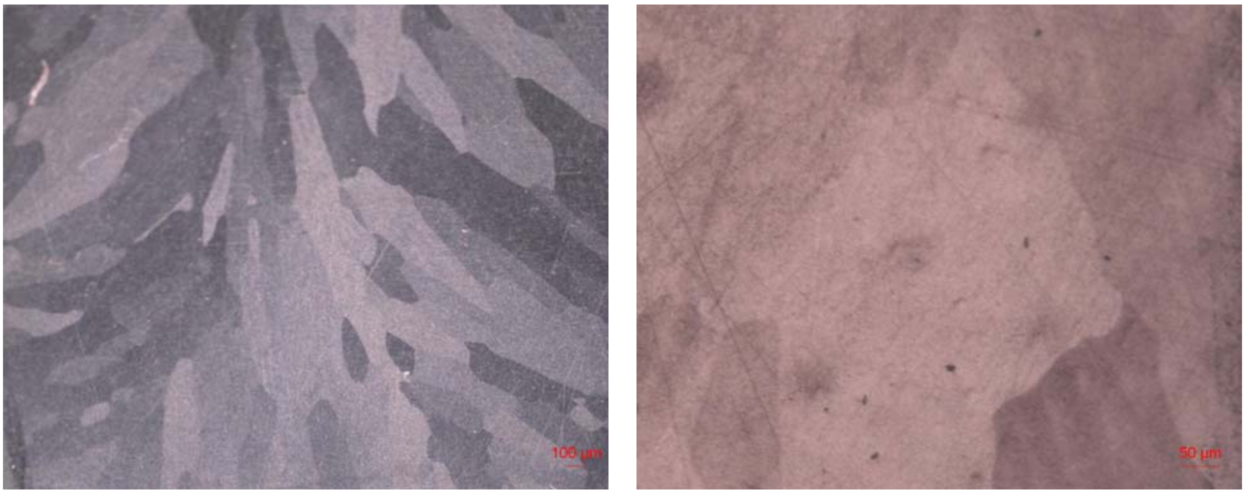

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Figure 15. Microstructure of the fusion zone of the 441 welded with ER430LNb and Ar

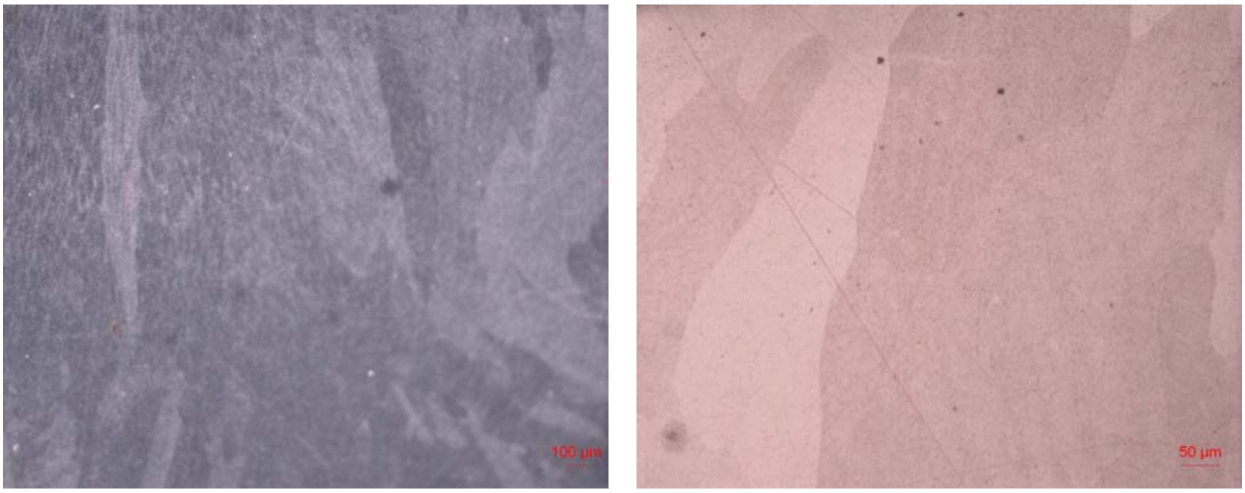

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Figure 16. Microstructure of the fusion zone of the 441 welded with ER430LNb and Ar+25%CO_2

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;
- The shielding gas didn't big differences in the weld bead structure formation;
- There is no formation of martensite with all the shielding gases used in this work;
- With the increase of the carbon dioxide content in the mixture with argon it has an increase in size of the grain when it is welded with ER430Ti;

5 ACKNOWLEDGEMENTS

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6. REFERENCES

BALMFORTH, M. C.; LIPPOLD, J. C. A New Ferritic-Martensitic Stainless Steel Constitution Diagram. Welding Journal, V. 79, n. 12, p. 339s-345s, Dec. 2000

DEARDO, A. J., Garcia, C. I.., HUA, M., TITHER, G., HULKA, K., Ferritic Stainless Steel - the metallurgy background and benefits of dual stabilization, In: Cong. Stainless Steels '96, Dusseldorf, p. 287-298, 1996.

DILLENBECK, V. R.; CASTAGNO, L. The Effects of Various Shielding Gases and Associated Mixtures in GMA Welding of Mild Steel, Welding Journal, pp 45-49 set. 1987.

JÖNSSON, P. G., MURPHY, A. B. and SZEKELY, J. Oxygen Additions on Argon-Shielded Gas Metal Arc Welding Processes, Welding Research Supplement - Welding Journal, V. 74, N. 2, p. 48-s 58-s, fev. 1995.

LIAO, M. T., CHEN, W. J., The effect of shielding-gas compositions on the microstructure and mechanical properties of stainless steel weldments, Materials Chemistry and Physics, 55, p. 145-155, 1998.

LUNDQVIST, B., Aspects of Gas-Metal Arc Welding of Stainless Steels, in Swedish. Sandvik AB, Sandviken, Sweden, 1980.

LYTTLE, K. A.; STAPON, F. G. Select the Best Shielding Gas Blend for the Application, Welding Journal, p 21 – 28, nov. 1990.

REDDY, G. M.; MOHANDAS, T. Explorative studies on grain refinement of ferrítico stainless steel welds. Journal of Materials Science Letters, 20, p 721-723, 2001.