SHIELDING GAS INFLUENCE ON THE DUCTILITY OF STABILIZED 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, novel ferritic stainless steel wires, stabilized with Nb and Ti, have been developed to tackle the target of matching the required mechanical properties and reducing the costs of ferritic stainless steel welds. However, the characterization of these wires concerning weldability aspects (operational and metallurgical) has not been accomplished yet. Thus, the aim of this work was to study the influence of the shielding gas composition (pure argon and combined with O_2 or CO_2) on the ductility loss in ferritic stainless steel wires stabilized with Ti and Nb. It was found that Nb promotes a better stabilization than Ti does when increasing the CO_2 fraction in the shielding gas.*

Keywords*: Ferritic stainless steel; Shielding gas; GMAW*

1. INTRODUCTION

The use of stainless steels has been nowadays widespread in a number of industry sectors. In the automotive industry, for instance, in general, the parts of the exhaustion system are composed of tubes and blanks (stamped metal sheets) that usually are welded and have ferritic stainless steels as the main base material, often used in the whole system. According to Alves et al. (2002), the main ferritic stainless steels used in the hot portion of automotive exhaustion systems are the AISI 409 and 441. On the other hand, in the cold portion, the AISI 409, 439 and 436 are normally utilized.

Faria (2006) states that automotive exhaustion systems went through a number of changes along the last 20 years as a consequence of more restrict pollution policies, needs for longer durability and higher engine efficiency and reduction in weight and costs.

Stainless steels used in the hot parts of automotive exhaustion systems, according to Sekita et al. (2004), must be refractory, have Niobium additions, contain higher levels of Molybdenum and the their Silicon amount has to be optimized. The same authors also mention the importance of having a good formability in such hot parts.

Renaudot et al. (2000) state that the welding of ferritic stainless steels with filler metals also made of ferritic stainless steels minimizes the metallurgical discontinuity around the weld bead and promotes a better metallurgical compatibility between the base metal and molten zone due to the small differences in microstructure and thermal dilatation. The authors point out that the ER409Nb filler metal has been utilized since the 90’s for welding low-Chromium ferritic stainless steels. Tests carried out with this wire resulted in welds with good geometry quality, ductility and resistance to intergranular corrosion.

Ferritic wires might contain different elements in their chemical composition such as Titanium, Niobium and Aluminum, as a way to improve mechanical properties and resistance to corrosion of the weld joints. Inui et al. (2003) tested three types of non-commercial filler metals made of stabilized ferritic stainless steels to also weld ferritic stainless steels; one stabilized with Titanium, one stabilized with Niobium and Aluminum and another one with Niobium, Titanium and Aluminum. The authors verified that the presence of Aluminum, Titanium and Niobium in adequate fractions is able to produce molten zones with fine grains and, therefore, better mechanical properties.

Madeira (2007) compared the results of the ER430Ti and ER430LNb using Ar+2%O2 as shielding gas. He noticed a higher penetration if the ER430Ti is used. This took place for the same welding setting (voltage and wire feed rate) in the power source and higher current levels were needed for the same fusion rate compared to the other wire. It was concluded that this higher penetration is related to the higher electrical resistivity of the ER430Ti wire in relation to that one found in the ER430LNb wire. Electrical resistivity values were measured by Resende (2007) in a comparative manner for the ER308LSi, ER430Ti and ER430LNb filler metals. He noticed that the first two wires had resistivity values relatively similar. The third wire, however, had lower resistivity levels. From the same reference, a comparison was made regarding the weld beads produced with ER430Ti and ER430LNb. It was observed that the weld bead appearance resulted from the ER430Ti utilization was significantly inferior (lower wetability and superficial quality). This fact was mainly linked to the ER430 superficial roughness, which resulted in an irregular feeding.

In spite of the references presented above, there is still lack of information concerning the weldability of ferritic stainless steels. Thus, this work intends to study the influence of some types of shielding gases on the welding process of two bi-stabilized (by Titanium and Niobium) ferritic stainless steels using filler metals also made of ferritic stainless steels. The resultant weld ductility was evaluated through a formability test for different shielding gases and three filler metals.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The material chose to work with was the AISI 441 for being largely used in hot parts of automotive exhaustion systems. This ferritic stainless steel has medium Chromium percentage and it is bi-stabilized by Niobium and Titanium. The base material used in this work was donated by ArcelorMittal and the company was responsible for the chemical composition analyses (Tab. (1)), which were carried out using optical spectometry.

Table 1. Base material chemical composition (data provided by ArcelorMittal)

MB	**Cr**	**C**	**N**	**Ti**	**S**	**Nb**	**ΔTi**	**ΔNb**
AISI 441	18,010	0,014	0,009	0,130	0,001	0,560	0,080	0,490

By using the stabilization equations for a bi-stabilized (by Niobium and Titanium) ferritic stainless steel elaborated by Fujimura; Tsuge (1999), presented by Eq. (1) and Eq. (2), the stabilization levels (ΔTi and ΔNb) were calculated. The stabilization values were similar for both Niobium and Titanium.

$$\Delta Nb = [Nb] - (0,7x7,74[C]) \quad (1)$$

$$\Delta Ti = [Ti] - 3,42[N] - (0,3x4[C]) \quad (2)$$

Two ferritic stainless steel filler metals with 1.0 mm in diameter were used; one stabilized by Titanium (ER430Ti) and one stabilized by Niobium (ER430LNb). Both wires were donated by ArcelorMittal, which was also responsible for the chemical composition analyses by humid technique. Tab. (2) presents the results of such analyses.

Table 2. Chemical composition of the filler wires used (data provided by ArcelorMittal)

Element	**C**	**N**	**Cr**	**Mn**	**Nb**	**Ni**	**S**	**Si**	**Ti**
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

By using the stabilization equations for the ER430Ti wire, the Titanium gradient was found to be negative (ΔTi = -0,130), that is, in this wire there is no sufficient Ti to be combined with all C and N present, mainly with all the C due to its high percentage. On the other hand, the ER430LNb had a positive Niobium gradient ((ΔNb = 0,123), that is, this wire has more stabilizing elements than enough to prevent the formation of Chromium carbides or nitrites and/or avoid the presence of interstitial elements in solid solution (capable to form austenite at high temperatures). Thus, it is possible to notice that the ER430LNb filler metal has a superior stabilization in relation to the ER430Ti one. This means that the ER430LNb is the most likely suitable wire for situations with high presence of Carbon and/or Nitrogen.

Five commercial gases were donated by WhiteMartins and used throughout the tests to have similar conditions found in the automotive industry; Ar, Ar+2%O_2, Ar+4%CO_2, Ar+8%CO_2 and Ar+25%CO_2. A multi-process power source was used and details of the experimental procedure can be found in Ferreira Filho et al. (2009).

The welding samples were taken from butt-welded plates. Plates made of the same joint material were used as backing as seen in the illustration in Fig. (1).

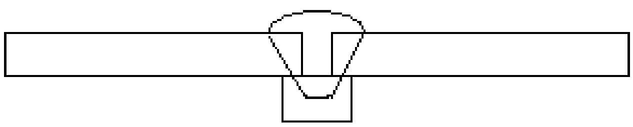


Figure 1. Configuration of the welding samples

The formability test was carried out on the weld face and root three times for each welding condition selected. This test was based on the ABNT NBR 5902 (1980) standard - *Determinação do índice de embutimento em chapas de aço pelo método Erichsen modificado*. Fig. (2) presents a schematic representation of the cross-section of the device used in the Erichsen test. Although the equipment did not have the recommended dimensions for the standard test, it was used anyway, as the main objective of the formability test was to develop a comparison for the welding conditions selected.

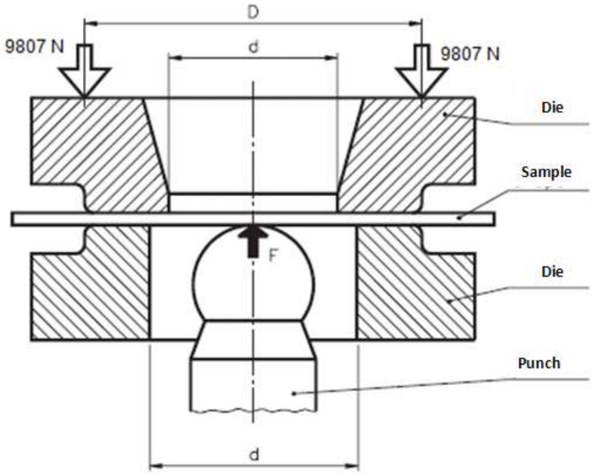


Figure 2. Cross-section of the device used for the formability test

Another important factor specified by the standard test is that a 9.807 N must be applied on the plate. As the device used for the formability test in this work has for bolts to fix the welding sample, a torque meter was utilized in order to check all the bolts and normalize the tests, as illustrated by Fig. (3). The torque applied to each bolt was calculated based on the standard in a way the plates were under the pressure specified.

Figure 3. Torque meter used to normalize the pressure applied on the welding sample before the formability test

The welding samples had 100x100x2 mm with the weld bead always in the center. The holes drilled on the plates had larger diameters than the fixing bolts to allow centralization of the weld bead in relation to the punch.

Vaseline was used to lubricate the plate/punch interface as it produces a situation similar to polyethylene. According to Madeira (2007) and Yasuda et al. (1984), when polyethylene or a similar lubricant is used, the participation of the molten zone in the deformation process is more effective than using substances like grease.

By using the formability test, information of the weld joint ductility is collected. Amongst the methods used to measure this ductility, some can highlighted with aid of Fig. (4); maximum force (MAX), maximum displacement (DMAX) that the punch had until the force starts to fall and the energy needed to accomplish the test, which is calculated by the area (A) below the force versupunch displacement curve. All these methods were used in this work.

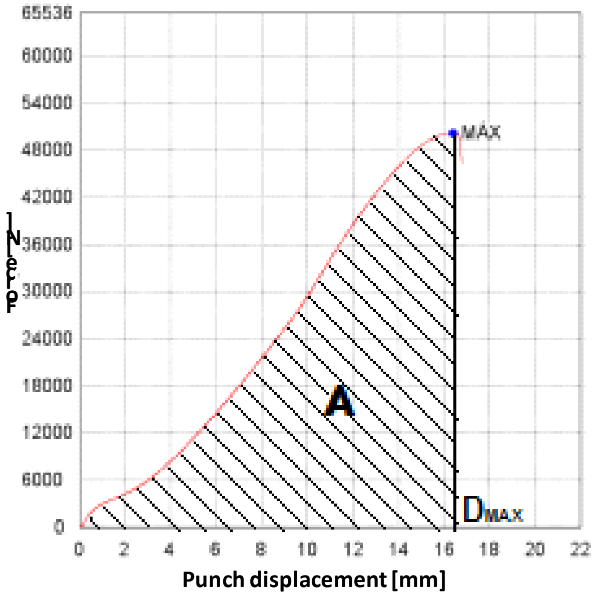


Figure 4. Force versus punch displacement curve for the formability test and maximum force (MAX), maximum displacement (DMAX) and energy (A) parameters

3. RESULTS

Tab. 3 presents the mean values and the correspondent standard deviations for the maximum force, maximum punch displacement and energy absorbed during the formability tests with the AISI 441 base metal and with the ER430Ti filler metal. Tab. 4 presents the formability test results for the ER430LNb filler metal.

Table 3. Mean values and the correspondent standard deviations for the formability test parameters with the AISI 441 base metal and ER430Ti filler metal

Shielding gas	**Side**	**F_{MAX} [N]**	**D. F_{MAX}**	**Disp. 10-3 [m]**	**D. Disp.**	**E [J]**	**D. E**
Ar	Face	48860	1764	15,6	0,6	371	44
Ar+4%CO_2	Face	22019	1571	8,2	0,4	81	10
Ar+8%CO_2	Face	6479	1909	3,5	0,8	12	5
Ar+25%CO_2	Face	4676	1132	2,2	0,8	7	3

F_{MAX} = mean maximum force; Disp. = punch displacement; E = energy; D. = standard deviation

Fig. (5), Fig. (6) and Fig. (7) present graphic results for the ER430Ti filler metal. As seen, all the factors analyzed had similar tendencies as the shielding gas was changed and the weld beads had lower values than the base metal for all the cases, fact also observed by Hunter; Eagar (1980), Sawhill; Bond (1976) and Redmond (1977). The parameters analyzed fall as the carbon dioxide fraction present in the shielding gas is decreased, that is, there is a fall in the weld bead ductility. This was more evident for the shielding gas containing 25% of carbon dioxide. As showed by Ferreira Filho et al. (2009), if the carbon dioxide fraction in the shielding gas used with the ER430Ti filler metal is increased, there is a micro-hardness increase, a grain size decrease, an increase in the number of precipitates and, for 25% of carbon dioxide, formation of martensite. All this effects justify the ductility fall tendency observed in the weld beads.

Table 4. Mean values and the correspondent standard deviations for the formability test parameters with the AISI 441 base metal and ER430LNb filler metal

Shielding gas	**Side**	**F_{MAX} [N]**	**D. F_{MAX}**	**Disp. 10-3 [m]**	**D. Disp.**	**E [J]**	**D. E**
Ar	Face	36063	6121	11,7	1,5	181	55
Ar	Root	29688	6901	10,5	1,8	142	61
Ar+2%O_2	Face	36771	13241	12,5	2,9	244	106
Ar+2%O_2	Root	23507	23616	8,6	6,9	158	235
Ar+4%CO_2	Face	30202	16777	10,6	4,1	203	125
Ar+4%CO_2	Root	32537	13936	11,3	3,8	207	141
Ar+8%CO_2	Face	20191	9038	10,2	0,3	101	33
Ar+8%CO_2	Root	20822	0	7,9	0	99	0
Ar+25%CO_2	Face	23390	2482	9,5	1,1	107	27
Ar+25%CO_2	Root	28135	7969	10,3	1,5	130	54

F_{MAX} = mean maximum force; Disp. = punch displacement; E = energy; D. = standard deviation

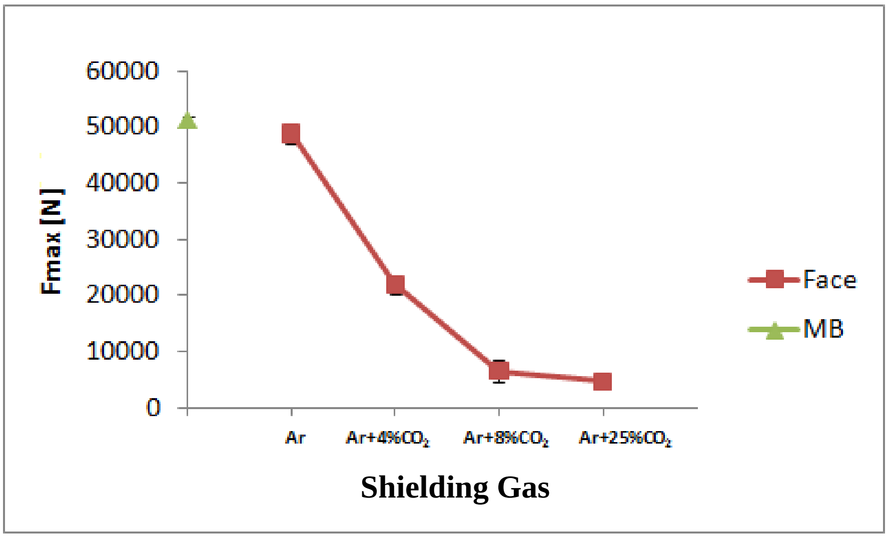


Figure 5. Maximum force applied by the punch in function of the shielding gas used with the AISI 441 base metal and ER430Ti filler metal

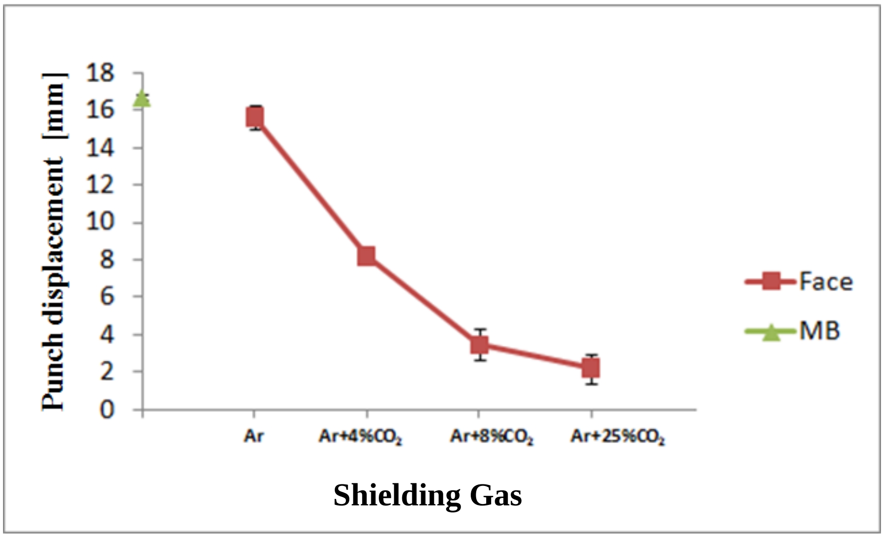


Figure 6. Punch displacement in function of the shielding gas used with the AISI 441 base metal and ER430Ti filler metal

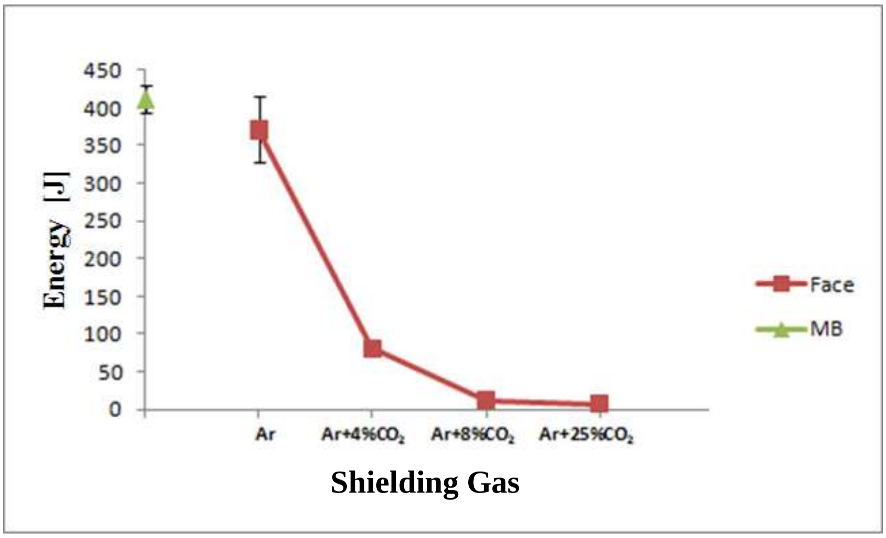


Figure 7. Total energy absorbed during the formability test in function of the shielding gas used with the AISI 441 base metal and ER430Ti filler metal

Fig. (8), Fig. (9) and Fig (10) present graphic results for the ER430LNb filler metal. All the factors analyzed had similar tendencies as the shielding gas was changed and in all cases the weld beads presented lower values than the base metal. In agreement with the results presented by Ferreira Filho et al. (2009), that show no significant changes in the weld bead microstructure and micro-hardness for the conditions used, neither the face nor the root of the weld beads showed any major variation of the factors analyzed as the carbon dioxide fraction was increased in the shielding gas. In this case, as showed in Tab. (1), the filler metal had an adequate stabilization. Besides this fact, Ferreira (2005), Guida (2006) and Hiramatsu (2001) state that the presence of Niobium can increase the formability of ferritic stainless steels, making the deformation of the weld sample easier.

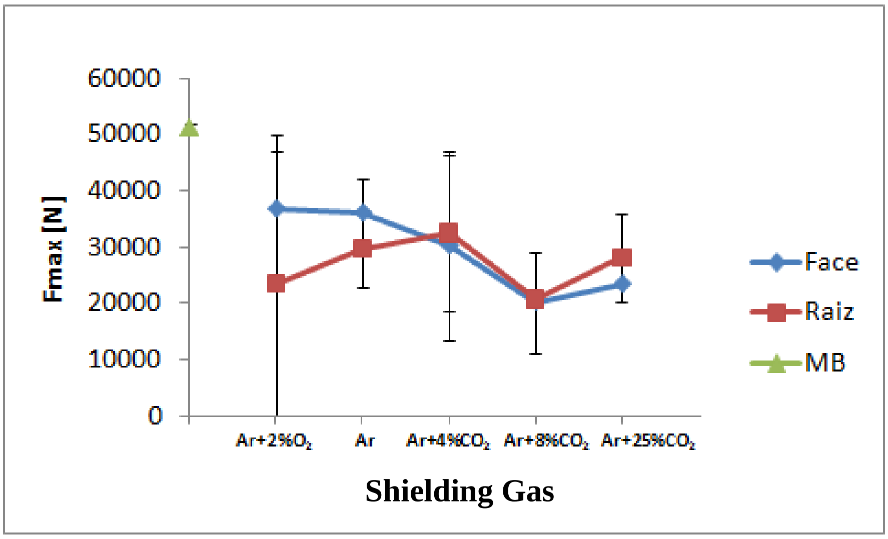


Figure 8. Maximum force applied by the punch in function of the shielding gas used with the AISI 441 base metal and ER430LNb filler metal

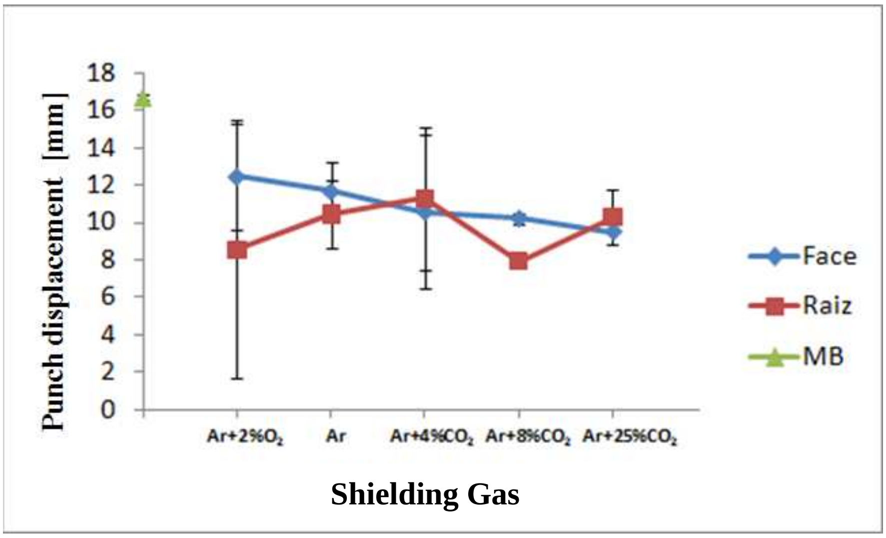


Figure 9. Punch displacement in function of the shielding gas used with the AISI 441 base metal and ER430LNb filler metal

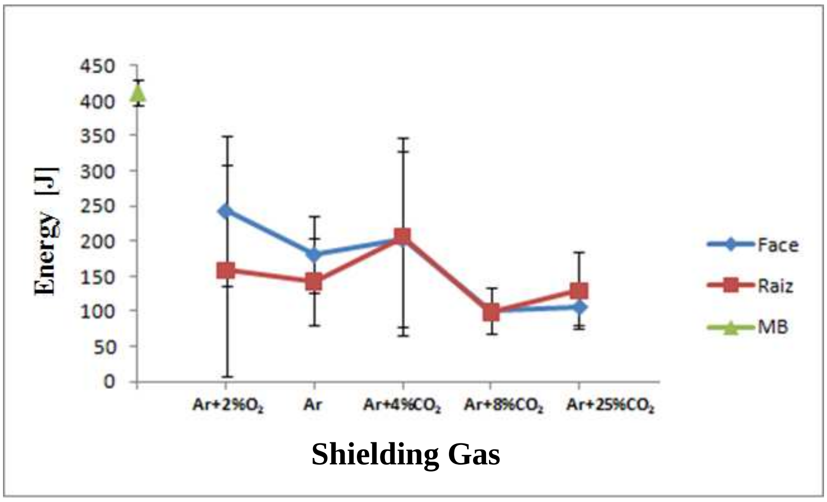
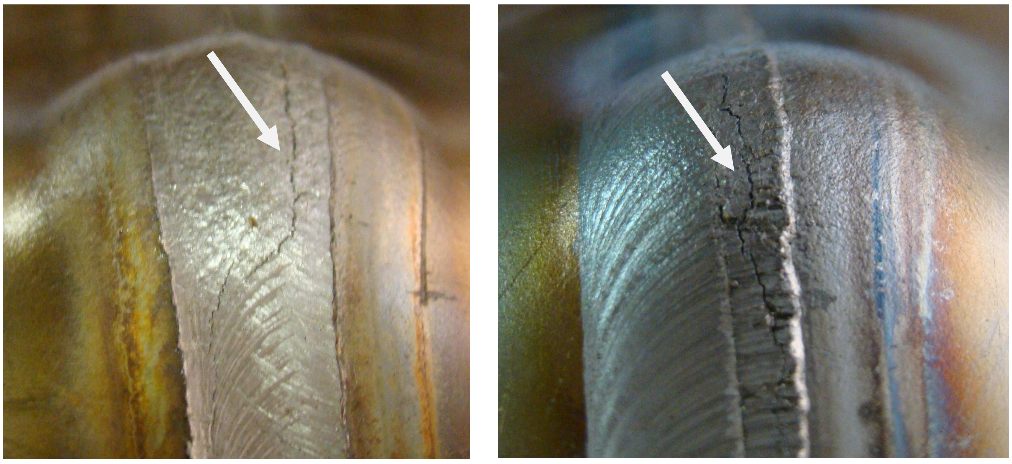


Figure 10. Total energy absorbed during the formability test in function of the shielding gas used with the AISI 441 base metal and ER430LNb filler metal

Fig. 11 presents the visual aspect of the cracks occurred during the formability test carried out in the root of welding samples produced with the UNS43932 base metal and Ar as shielding gas for both the ER430Ti (a) and ER430LNb (b) filler metals. As seen, the cracks took place parallel to the welding direction at the deformed portion produced by the punch. On the other hand, for the weld beads produced with 25% of carbon dioxide, the fracture took place transversally to the welding direction, as illustrated by Fig. (12). Madeira (2007) also noticed both forms of fracture in his tests and states that transversal cracks help during the formability test measurements as they ensure that the ductility assessment is being carried out for the welded region.



a b

Figure 11. Visual aspect of the cracks occurred during the formability test carried out in the root of welding samples produced with the UNS43932 base metal and Ar as shielding gas for both the ER430Ti (a) and ER430LNb (b) filler metals

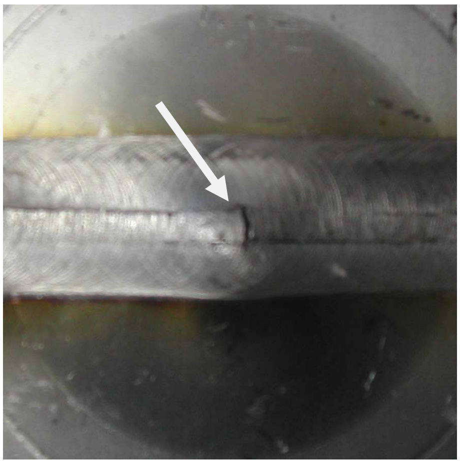


Figure 12. Visual aspect of a crack occurred during the formability test carried out in the root of a weld bead produced with the UNS43932 base metal, Ar+25%CO_2 as shielding gas and the ER430Ti filler metal

4. CONCLUSIONS

Taking into account the results discussed above, the conclusions can be summarized as:

- The weld beads produced with the ER430Ti filler metal presented a ductility fall (measured by the formability test) as the carbon dioxide fraction in the shielding gas was increased;
- In contrast, the weld beads produced with the ER430LNb filler metal did not show any significant change in their ductility (measured by the formability test) regardless of the shielding gas and base metal utilized.

3. ACKNOWLEDGEMENTS

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