

# **ANALYSIS OF SENSITIZATION IN WELDED JOINTS IN FERRITIC STAINLESS STEEL WITH TUBULAR WIRE STABILIZED AND BISTABILIZED**

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## **ABSTRACT**

The present work aims to analyze the interaction and the susceptibility to intergranular corrosion in welded joints of carbon steel and AISI 409 stainless steel welded with tubular-like stabilized titanium and bistabilized with titanium and niobium. The corrosion susceptibility tests were carried out in 10% oxalic acid with electrolytic analysis to characterize stainless steel sensitization and metallographic analysis with Nital etching to characterize carbon steel. It can be observed the grains formed in the joint with bistabilized wire are smaller in both (TAZ) thermally affected and molten zones. Based on the results it is discussed the use of niobium as stabilizer of the welding wire and obtaining a welded region more resistant to intergranular corrosion.

## **BACKGROUND**

In searching for better performance, on the competitive automotive scenario, many companies have chosen for raising the durability of their components, as most commonly observed damage is on the exhaustion system, and on these damages 80% are caused by corrosion and 20% are resulted of fatigue.

The choice of stainless steel is effectively shown, as this grade of steel presents high corrosion resistance in various environments. Its predominant is chromium with minimum concentration up to 11%. The corrosion resistance also can be improved by adding nickel, titanium, niobium and molybdenum.

Stainless steels may be classified based on their predominant microstructure, such as martensitic, ferritic or austenitic.

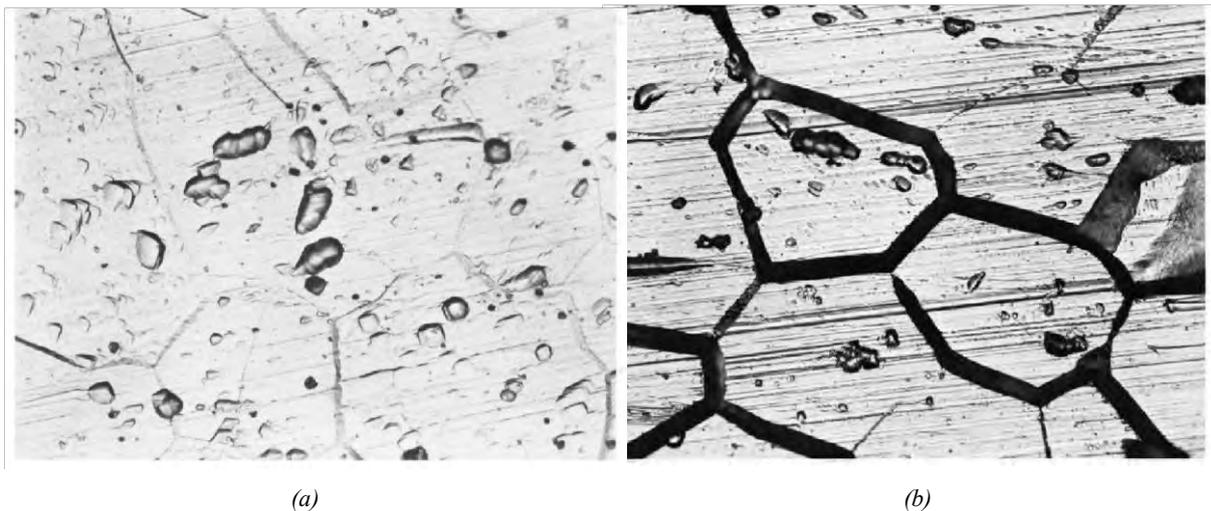
The ferritic stainless steel consists of binary iron-chromium alloys, with chromium content in the range of 11 to 30% and carbon content below 0.12% and no nickel addition. They are used in production of electro domestics, kitchen and laboratory tools, on high temperature applications such as exhaustion and discharge of smoke from combustion of petroleum derivate, nuclear energy, etc; and normally, almost all those applications, the steel is submitted in welding process .

The most common problem in welding of stainless steel is the occurrence of intergranular corrosion; it is caused<sup>[MAC1]</sup> by the impoverishment of chromium at the steel grain boundary, due to affinity between carbon and chromium, it makes the free chromium moves to grain boundary, forming carbon carbides. The lack of chromium avoids the formation of a passive layer that protects the stainless steel and makes it susceptible to corrosion. This phenomenon is called sensitization.

The stabilization of stainless steel with titanium has the objective to make it less susceptible on intergranular corrosion and improve its mechanical strength. It is also common the use of biestabilization, and the niobium and titanium are also used in the process.

As consequence of addition of niobium on the welding bead it is more likely that que majority of the precipitates formed inside of stainless steel are constituted of carbides (NbC), nitrides (NbN and TiN) and Laves phase (Fe<sub>2</sub>Nb). Considering the C-Nb affinity, it is possible to argue that, rarely will form the chromium carbide (CrC), and the stainless steel will be less susceptible to sensitization phenomenon.

According to the ASTM A763 the ferritic stainless steel is susceptible to intergranular corrosion when they show valeted grain contours or with ditches, in other words, susceptible to corrosion after test, as shown on the first figure.



*Figure 1- ASTM A763 (a) Acceptable structure of ferritic stainless steel after test. (b) Unacceptable structure, presenting intergranular corrosion on the stainless steel after test.*

## **EXPERIMENTAL**

The chemical composition of the steels used in this scientific research, as the welding beads are presented on the Tables 1 to 4.

The Table 1 to 5 show the specifications and the welding parameters.

Table 1 – Chemical composition of SAE 1010/20 – ASTM A36 carbon steel.

ASTM	%C	%Mn	%P	%S	%Cu
A 36	0.26	0.75	0.04	0.05	0.2

Table 2 – Chemical composition of the AISI 409 ferritic stainless steel.

AISI	DIN	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Mo	%N <sub>2</sub>	%Outros
409	1.4512	0.03	1.00	1.00	0.04	0.02	10.5 a 11.7	0.5	-	0.030	6(C+N <sub>2</sub> ) <= Ti <= 0.50

Table 3 – Chemical composition of the AISI 409 Ti – monostabilized welding bead.

AISI	%C	%Mn	%P	%S	%Si	%Cr	%Ti
439 Ti	0.02	0.68	0.010	0.010	0.56	17.90	0.80

Table 4 – Chemical composition of the AISI 409 Ti e Nb – bistabilized welding bead.

AISI	%C	%Mn	%Si	%P	%S	%Cr	%Mo	%Cu	%Ni	%Ti	%Nb
439 Ti	<	<	<	<	<	17.0	<	<	<	10xC	10xC
Nb	0.03	0.80	0.80	0.03	0.03	- 19.0	0.50	0.75	0.60	- 1.1	- 0.6

Table 5 - Welding condition, parameters

Wire	AISI 409 Ti	AISI 409 Ti e Nb
Current (A)	325	295
Welding speed (mm/s)	25	25
Tension (V)	27.3	21.3
Arc Length	-18	-15
Gas	AG12	AG12

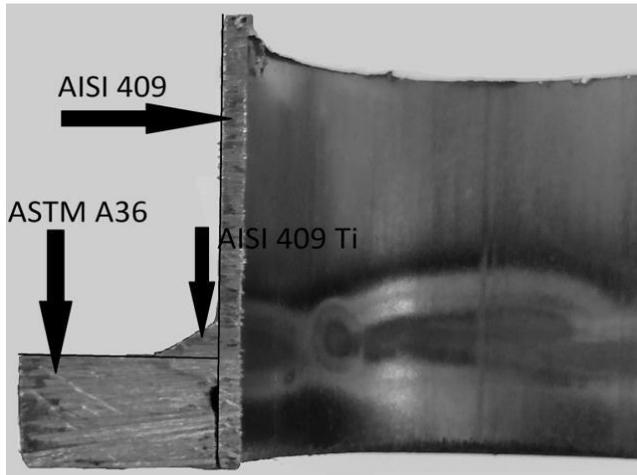


Figure 3 – Sample which used the AISI 409 Ti welding bead.

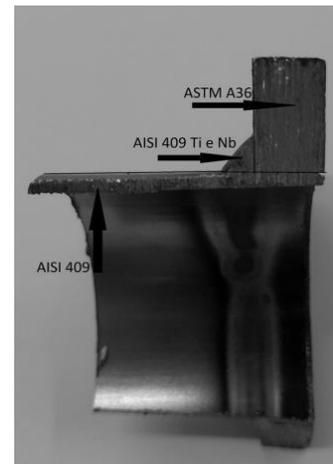


Figure 4 – Sample which used the AISI 409 Ti e Nb welding bead.

In this work were removed two samples of automotive exhaust system, the sample number one, was manufactured in welding of a carbon steel ASTM A36 flange and a stainless steel AISI 409 flange, the welding wire used was bistabilized with Nb and Ti stainless steel. The sample number 2 was also produced of welding in carbon steel ASTM A36 flange and a stainless steel AISI 409 flange, differences between both samples are in the welding bead, that was made using a AISI409TiNb bistabilized bead.

This study has started with receiving of samples from a local carmaker. After being adequately cut and separated, they were identified as following: sample 1 was welded with AISI409 bistabilized on Ti and Nb welding bead and sample 2 was welded with AISI 409 monostabilized on Ti.

The samples submitted in to metallographic analysis were prepared following the ASTM E3 standards, using sandpapers A220, A320, A400 and A600, after they were polished with 1 to 3  $\mu\text{m}$  diamond paste.

The corrosion tests were performed according to the ASTM A763 standards with electrolytic acid etching using oxalic acid (10%) to characterize the susceptibility for intergranular corrosion.

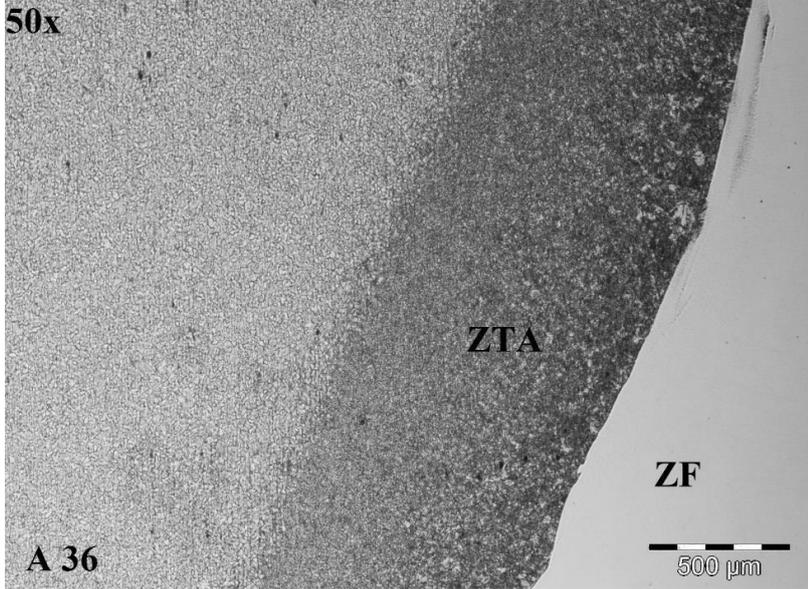
Due the high corrosion resistance of the stainless steel, it is impossible to observe the metallography of both samples with the same test. In other words, a test that characterize the A36 carbon steel wouldn't be effective to attack the AISI409 stainless steel, and an attack that could characterize the stainless steel would be too much for the A36 carbon steel.

The metallographic tests were performed using 2% nitric acid etching, although it is not sufficiently aggressive to a metallography in AISI409 stainless steel, which is because it was used to observe the A36 in both samples 1 and 2.

The corrosion testing using 10% oxalic acid in accordance with ASTM A763, is capable of etching the AISI409 stainless steel, both at the weld and at the flange, but it over attacks the A36 carbon steels from the exterior tube making the micrography completely black. In this case, the same attack used to characterize the sensitization was used as metallography of the stainless steel.

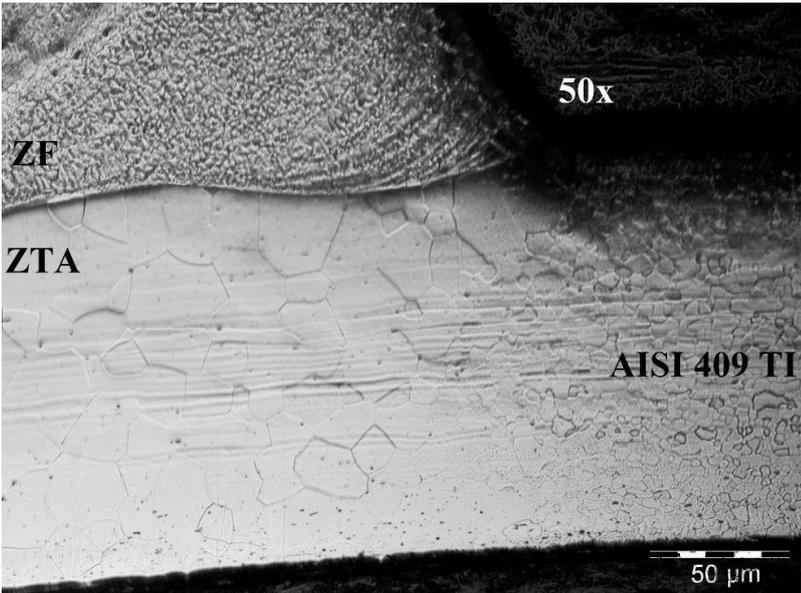
**RESULTS AND DISCUSSION**

Figure 5 shows the thermally affected zone (TAZ) and the base metal of the ASTM A36 carbon steel. It is possible to observe the molten zone (FZ) that was not affected by the nitric acid etching.



*Figure 5 –Metallography of the ASTM A36 carbon steel and the molten zone. Etching with 2% nitric acid. 50x magnification. Sample 1 (bi-estabilized welding bead).*

The Figure 6 shows the molten zone near to stainless steel, the TAZ and the metal base of the AISI409Ti stainless steel. Note differences in sizes of the TAZ region and the base metal, and it is also related with grains growth in the stainless steel.



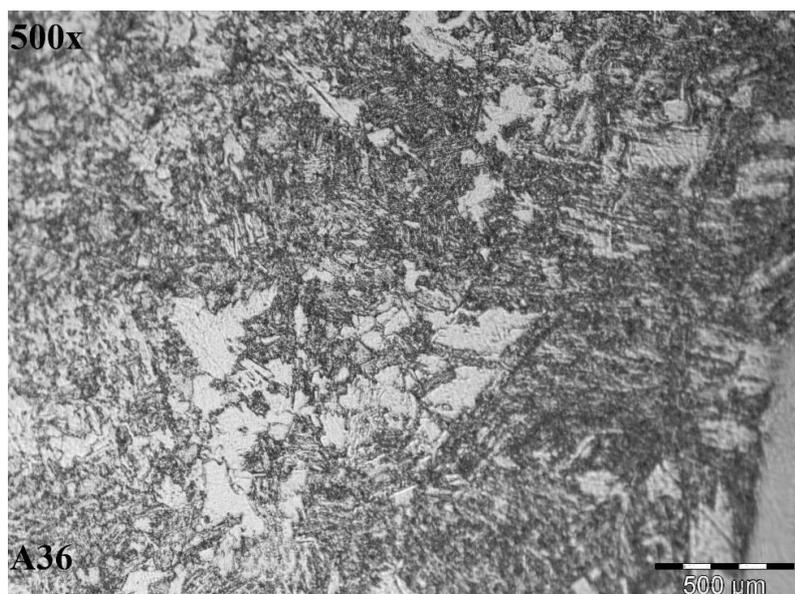
*Figure 6 – Metallography of the ASTM A36 carbon steel and the molten zone. Etching with oxalic acid (10%). 50x magnification. Sample 1 (bi-estabilized welding bead).*

The Figure 7 shows the A36 carbon steel in the region Non-Affected by the welding process. It is possible to see characteristics of the steel in a region far from welding bead, it was not affected by the temperature, and the microstructure is composed by perlite e ferrite.



*Figure 7 – Metallography of the ASTM A36 base metal. Etching with 2% nitric acid. 50x magnification. Sample 1.*

The Figure 8 shows the thermally affected zone (TAZ) by the welding of the A36 carbon steel. It is possible to observe the microstructural characteristic of the steel in contact local with the welded region. The micrograph is composed by perlite, uncircular ferrite and probably martensite. For confirming the presence of martensite would be necessary to perform another etching with a specific reagent or submit samples in microhardness test.



*Figure 8 – Metallography of the TAZ of the ASTM A36 carbon steel. Etching with 2% nitric acid. 500x magnification. Sample 1.*

Figure 9 shows the base metal of the AISI 409Ti stainless steel, in the region where the base metal was not affected by the welding heat. In this region is possible to see the refined grains and lack of precipitates or vaillets on the contour of grain.

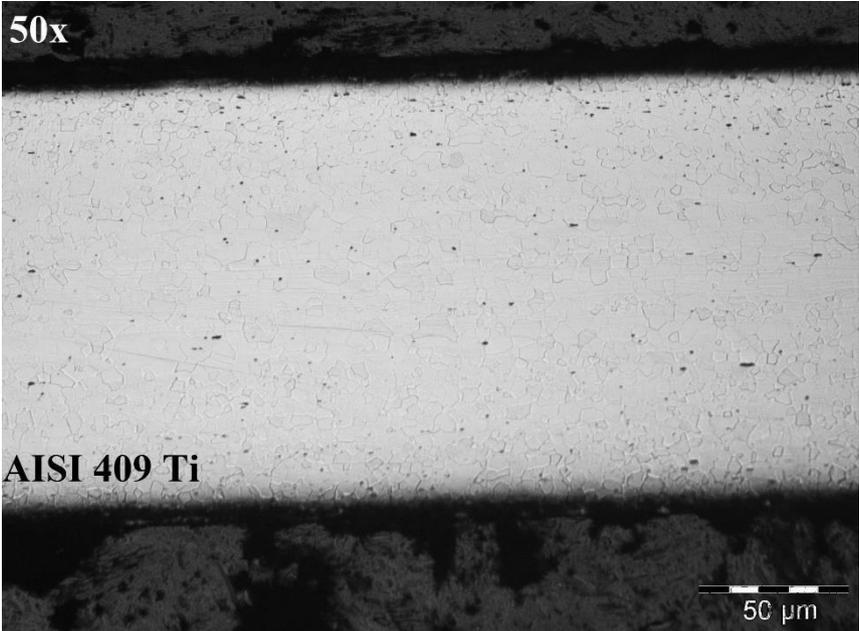


Figure 9 – Metallography of the AISI 409 stainless steel metal base. Etching with oxalic acid (10%). 50x magnification. (bistabilized welding bead).

The Figure 10 shows the thermally affected zone (TAZ) of the stainless steel. This is the closest region of the welding, where it is possible to see the growth of the ferritic grain when compared to the grains showed in Figure 9.

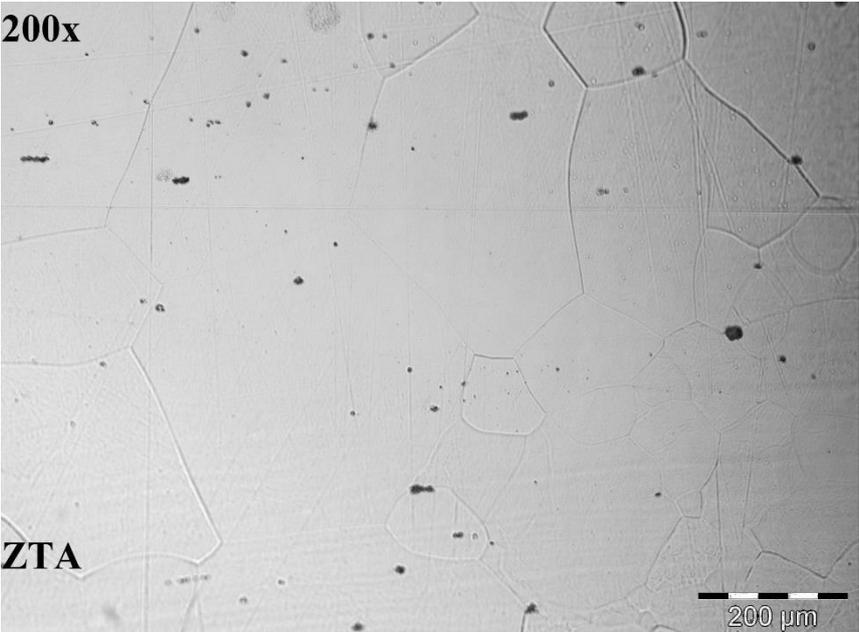


Figure 10 – Metallography of the TAZ in AISI 409 stainless steel. Etching with oxalic acid (10%).200x magnification. Sample 1 (bistabilized welding bead).

The Figure 11 shows the molten region belonging to sample 1, which was welded with bistabilized welding bead. Besides of refined grains, we can observe that the closest region to the A36 carbon steel presents valeted grains, and the grains close to the AISI409 stainless steel present themselves in steps. That means that the grains close to carbon steel are more susceptible to intergranular corrosion even with the addition of niobium, since higher carbon content in this region influences positively the formation of chromium carbides.

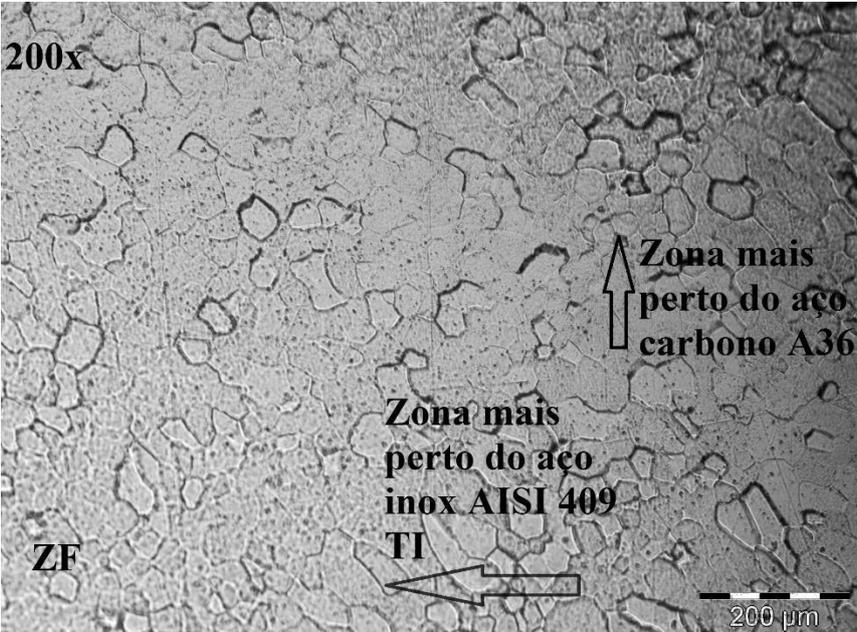


Figure 11 – Metallography of the molten region of the AISI 409 stainless steel. Etching with oxalic acid (10%).200x magnification. Sample 1 (bistabilized welding bead).

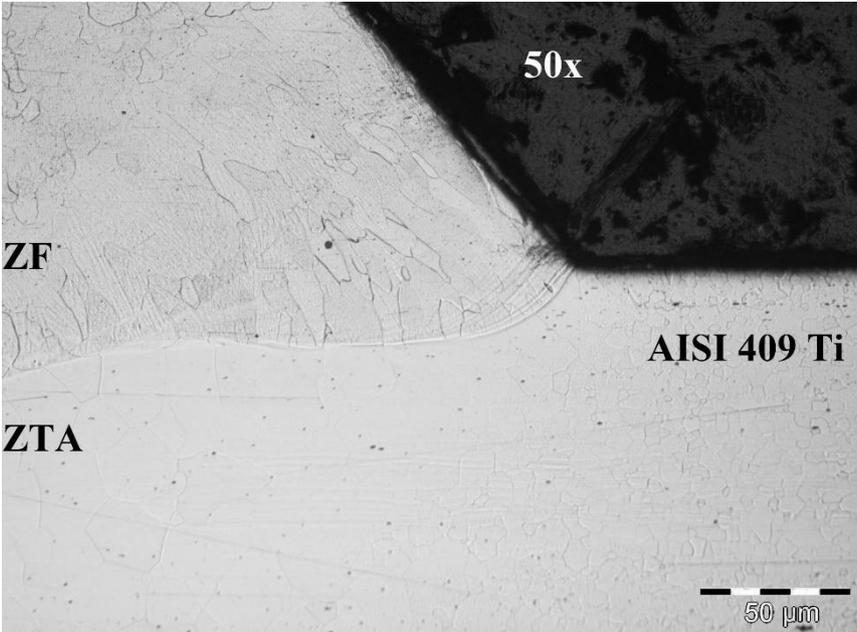


Figure 12 – Metallography of the AISI 409 stainless steel and the molten region. Etching with oxalic acid (10%). 50x magnification. Sample 2 (monostabilized bead).

The Figure shows the molten region, TAZ and the base metal of the AISI409 stainless steel. It is possible to note that the FZ and TAZ grains are bigger than the sample 2 (Figure 12), in which the welding was performed with monostabilized welding bead, in comparison with sample 1 (figure 6), in which the welding was performed with bistabilized welding bead.

## **CONCLUSION**

The current study concluded that joint welded by bistabilized welding bead, both in molten and thermally affected zones presented smaller grains when compared to the grains in the joint welded with monostabilized welding bead.

The sample welded with bistabilized welding bead presents bigger precipitation in grain boundaries; on the other hand, even most valeted grains are not forming ditches.

The molten region (FZ) near to A36 stainless steel presented more valeted grains than region close to the AISI 409 stainless steel and, thus, more susceptible to intergranular corrosion even the niobium addition. Possibly, the higher carbon content presents on the region may have been favoring the precipitation of chromium carbide.

## **ACKNOWLEDGMENTS**

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## **CONTACT INFORMATION**

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## **REFERENCES**

ASTM E3 – 11 Standard Guide for Preparation of Metallographic Specimens.36

ASTM A763 – 14 - Standard Practices for Detecting Susceptibility to Intergranular Attack in Ferritic Stainless Steels.

CAMPBELL, R. D. Ferritic Stainless steel Welding Metalurgy. Key Engineering Materials, v. 69 & 70, p 167-216, 1992.

FARIA, R. A. Efeito dos elementos Ti e Nb no comportamento em fadiga de aços inoxidáveis ferríticos utilizados no sistema de exaustão de veículos automotores. 2006. 245f. Doutorado em Engenharia de Materiais – Universidade Federal de Ouro Preto, Ouro Preto, 2006.

Serna-Giraldo, Carlos. Resistência à corrosão intergranular do aço inoxidável ferrítico UNS S43000: avaliação por método de reativação eletroquímica, efeito de tratamento isotérmico e mecanismo de sensibilização. 2006. Doutorado em Engenharia Metalúrgica e de Materiais – Universidade de São Paulo, São Paulo, 2006.

V.S. Moura, L.D. Lima, J.M. Pardal, A.Y. Kina, R.R.A. Corte, S.S.M. Tavares. Influence of microstructure on the corrosion resistance of the duplex stainless steel UNS S31803, *Materials Characterization* 59 (8), 1127-1132, 2007.

William D. Callister, Jr., David G. Rethwisch. *Ciência e engenharia de materiais uma introdução*, 9ª edição, 2016. LTC .