EVALUATION OF WELDED JOINT WITH FERRITIC STAINLESS STEEL AISI 439 APPLIED IN EXHAUST MANIFOLD OF AUTOMOTIVE VEHICLES

Fabio Noveli Faggian[1];Gustavo Victor Relva Rollo[1]; Susana Marraccini Giampietri Lebrão[1]; Marco A. Colosio[2]; José Agustín Castillo Lara[3]

1 Centro Universitário do Instituto Mauá de Tecnologia;
2 General Motors Mercosul;
3 Fundação Santo André

ABSTRACT

The present study focus on analysis in exhaustion system welded joints constituted of AISI 439 seamless steels and an ASTM 36 steel flange, by application of 430Ti solid wire. The joints were heated in oven at 650°C and 750°C for 50h and 100h. The intergranular corrosion susceptibility was evaluated according to ASTM A763, it was used electrolytic etch under 10% Oxalic Acid. Samples were characterized metallographically by application of Nital etch in iron-carbon region and Villela in seamless steel part, besides that, Vickers hardness profiles on different regions were also performed.

1. BACKGROUND

For the past 30 years, the automotive exhaust system has undergone several changes aimed at optimizing performance; improve engine efficiency and consequently higher reducing fuel consumption; reduction of weight and minimization of emissions of polluting gases; enhance durability as the main damages observed in the automotive exhaust system 80% is attributed to corrosion and the remaining 20% to fatigue (LIEWELLYN, 1994).

In the words of Modenesi (2001), ferritic stainless steels have a low coefficient of thermal expansion, good machinability, satisfactory ductility and toughness, albeit smaller when compared to austenitic stainless steels. Furthermore, Chawla (1995) and Modenesi (2001) mention that this group of steels have a lower corrosion resistance than austenitic stainless steels. The main advantage of these steels is their corrosion and oxidation resistances aligned with competitive price compared to other stainless steels.

For application in the exhaust manifold it's recommended specifies ferritic stainless steels due to their lower coefficient of thermal expansion in comparison to austenitic stainless steels, as consequence, they strain less at high temperatures, which certainly improves the part design of in vehicle exhaust system, such as exhaust manifold, adding some advantages from the point of view of cost and lightweight. Hence as the deformation in these steals is smaller, the ferritic stainless steels are more adequate for applications where there is thermal cycling occurs (due to less presence of oxide detachment), so this is indicated to exhaust system and especially of the exhaust manifold (DI CUNTO, 2005).

2. EXPERIMENTAL

The chemical composition of steels AISI 439, ASTM36 and the 430 Ti tubular weld wire, and the welding parameter used are shown in Tables 1 and 2.

Table 1: Chemical composition of steels AISI 439, ASTM36 and Ti tubular wire 430 Ti (A.T.430Ti).

Chemical composition (% in mass)									
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Ti**	**Mo**
ASTM36	0,18 - 0,23	0.10	0,30 – 0,60	0.03	0.035	-----	-----	-----	-----
AISI 439	0.0080	0.4700	0.2400	0.0300	0.0004	17.23	0.2700	0.1320	0.0280
A.T.430Ti	0.0210	0.7400	0.7500	0.0210	0.0010	17.74	0.2500	0.3800	0.0300

Ref: Own Authorship.

Table 2: Specifications and Welding Parameters using to produce the specimens

METAL CORED WIRE PARAMETERS

Program = 10
CrNi => 18 - 8 – 6
WIRE =1,2 =>MC439Ti
Amperage = 325 A
Arc Stream Voltage = 27,3 V
Inductance= -5
Arc Length -18
Welding Speed= 25

Ref: Own Authorship.

The specimens were heated at 650ºC and 750ºC for 50 and 100h. This temperature range was obtained with a thermocouple installed in the exhaust manifold of a gasoline 1.4 engine, mounted in a test bench; The measurements were acquired in the range of operation at a section of higher temperature.

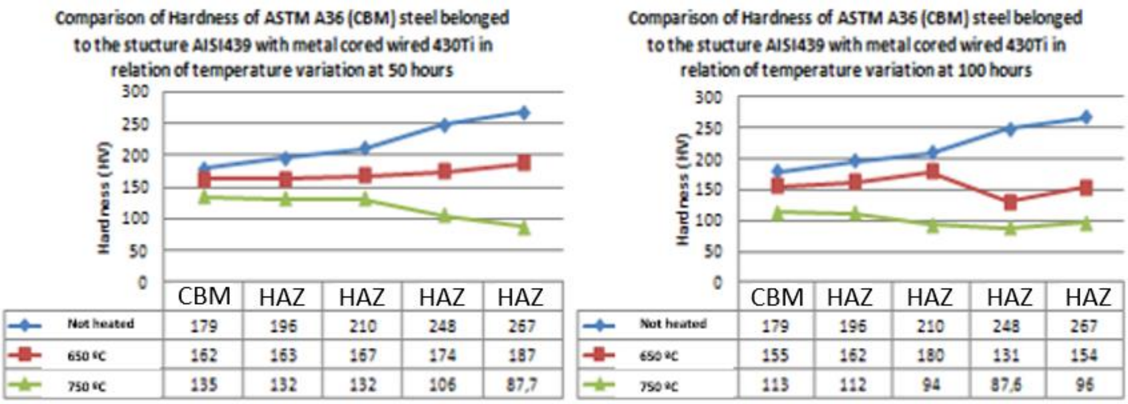
The specimens were analyzed using Villela, Nital and 10% oxalic acid etch and ASTM 763 standard, to characterize susceptibility to intergranular corrosion.

The microhardness tests were performed according to the ABNT NBR NM ISO 6507-1 standard, using the microdurometer, model Vickers402 MVD, applying loads of 1000 grams in each of the executed impressions.

3. RESULTS AND DISCUSSION

For the analysis of the A36 steel region, were performed Nital 3% etching and microhardness tests. For being a mild steel, it is possible to identify that the microstructure of this steel is composed of ferrite (α) and Perlite (P). Due to overheating provided by the welding process the structure in question, presented low carbon martensite transformation in the heated affected zone (HAZ) at the border with the region of the fusion zone (FZ) and grain boundaries refining, which can be confirmed by the hardness curve of the specimens without heat exposure, see figure 1 chart A and B.

Figure 1: Comparison of Hardness of ASTM A36 (CBM) steel belonged to the structure AISI439 welded with metal cored wired 430Ti in relation to temperature variation at (A) 50 hours; (B) 100 hours.



Ref: Own Authorship.

Comparing the effect of temperature, it was observed a certain hardness reduction occurred due to temperature increase. A plausible hypothesis for this is the stress relieve, especially in the martensite, and the increase of the grain size and decarbonization, both are evidenced through the metallography. It is noteworthy that for specimens heated to 650 °C there was small decarbonization located only at the border of the heated affected zone (HAZ) with the fusion zone (FZ) while the grain increase wasn't significant, generating the hypothesis that the hardness decreases for these samples is mainly due to stress relieving, check little divergence comparing metallography for 50 and 100 hour times.

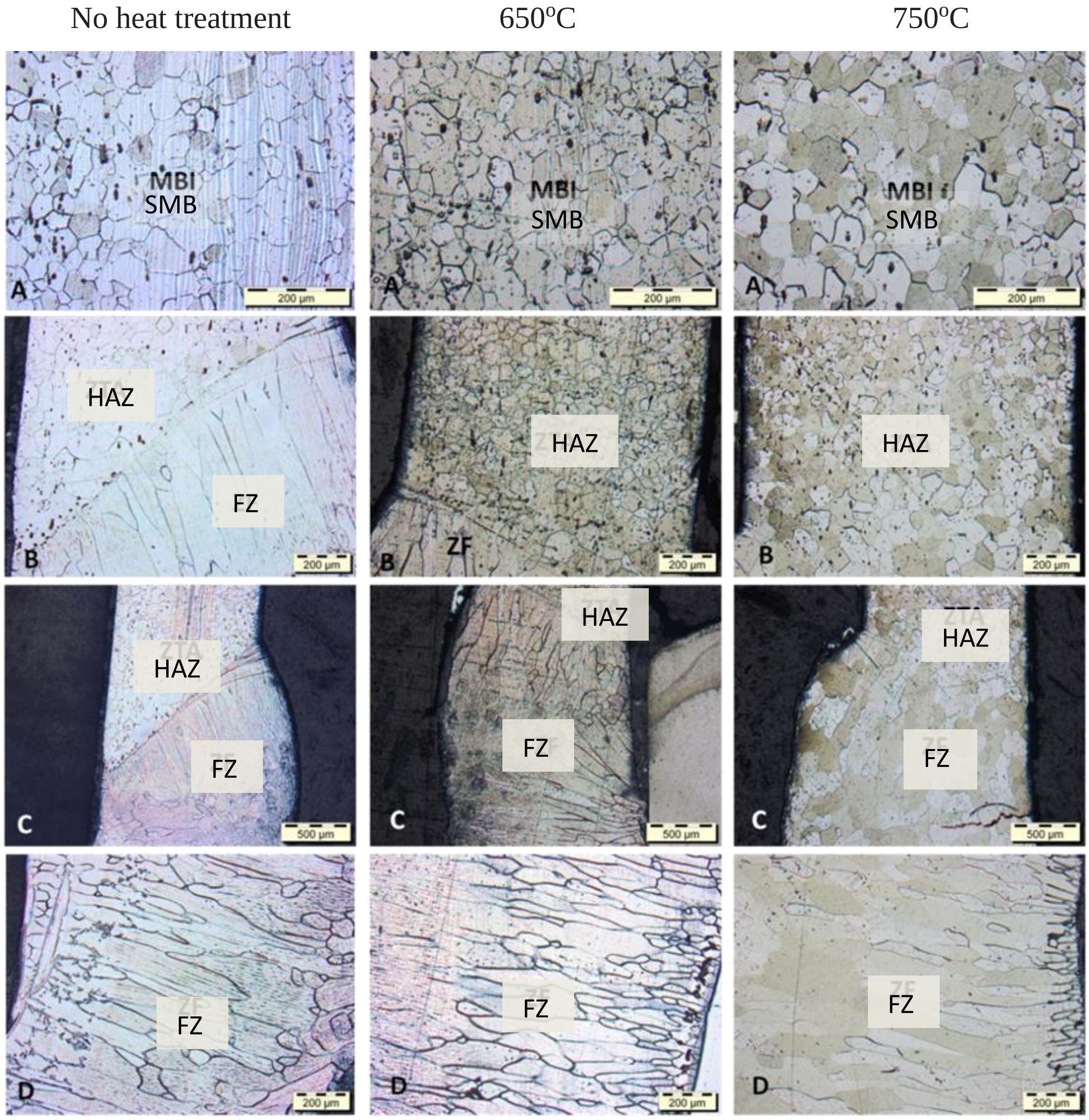
For the specimens heated to 750 ° C, it's possible to observe the increase of the grain on the region of the HAZ and a decarburization, in conjunction with the stress relieving are responsible for decreasing the hardness, so the effect of the decarburization and increase of the grain size is more considerable for samples heated by 100 hours than samples heated by 50 hours. Therefore, it's possible to conclude that the increase in temperature was more expressive than the effect of time. Thus, as the A36 steel is not the main object of study of this present work, metallography photos will not be attached in.

3.1. TEMPERATURE INTERFERENCE

In order to verify the presence of chromium carbides at intergranular region and analysis of sensitization behavior in different samples exposed at different temperatures and times, the electrolytic etching with 10% oxalic acid was used and characterize the microstructure of the fusion zone (FZ), Villela etching and hardness tests were carried out to check possible effects due to exposure to temperature and time.

Figure 2 shows the microstructures of the samples of the structure formed by AISI 439 and AISI 430Ti, at different temperatures. Observing region A, which illustrates the region of the stainless steel base metal (SBM), the samples had a similar behavior against corrosion, it can be seen that the SBM region of the AISI 439 steel, which is non-stabilized and belong to ferritic group, have ferritic microstructure with precipitates rich in chromium, in order words, chromium carbides and /or chromium nitrides, which come up mostly in the intergranular form, due to the supersaturated amount of chromium and nitrogen in ferrite, with structure presenting grains classified as "step" and a few grains with contour characterized as "dual" and "ditch."

Figure 2: Temperature effect of the structure formed by AISI439 steel and metal cored wired AISI 430Ti specimens heated for 50 hours etch with oxalic acid 10%. (A): stainless steel base material (SBM) - 200x. (B): Heat affected zone (HAZ) - 100x. (C) Fused Zone (FZ) - 50x. (D) Fused Zone (ZF) - 100x.

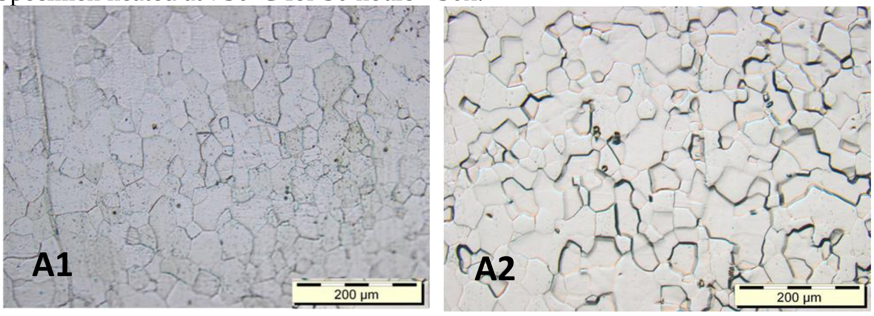


Ref: Own Authorship

Analyzing the heat affected zone of the specimens without heating exposure, represented by B in figure 2, it is possible to identify sensitization in some points identifying mostly grains “step” type with the presence of some little grain "dual" and "ditch" type, as described in ASTM A763 (1999).

Regarding the geometry and grain size, the effect of temperature wasn’t significant as illustrated in Figure 3, because it has a high concentration of alloying elements increasing the capacity to retain grain increase with the effect of temperature as mentioned by Modenesi (2001), the effect of the temperature caused a gradual reduction of hardness, the specimens not subjected to temperature had an average hardness of 165HV while the specimens submitted to 750ºC had a hardness of 150HV.

Figure 3: Temperature effect in Stainless Base Metal (SBM) of the structure formed by AISI439 steel and metal cored wired AISI 430Ti specimens etch with Villela. (A1) Specimen heated at 650°C for 50 hours - 50x. (A2) Specimen heated at 750°C for 50 hours - 50x.



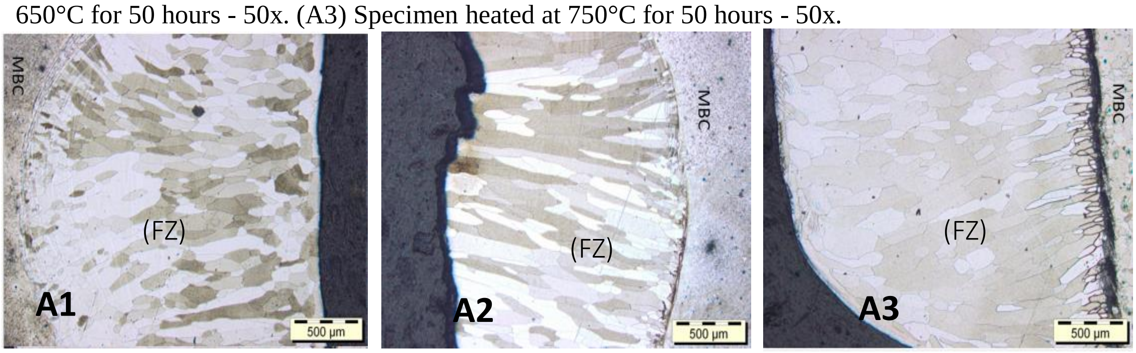
Ref: Own Authorship

Heating at 650°C and 750°C most of the grains have a "ditch" structure, but for specimens heated to 750°C occurred less sensitization than the heated specimens at 650°C. A hypothesis for this phenomenon is due to the precipitation of secondary phases in grain contours such as chromium carbide and the presence of a higher percentage of alloying elements present in the steel.

The temperature analysis shows a strong presence of titanium carbides dispersed in the fused zone (FZ), which can be observed in C and D region of figure 2, in the specimens without heating and heating at 650°C, the amount of the carbides of titanium is practically the same. However, it was noted that for the specimens heated to 750°C, it was not possible to verify exactly the formation of titanium carbides. Still in the region of the fused zone (FZ), for the specimens without heat exposure a low degree of sensitization in the proximity of the heat affected zone (HAZ) of the stainless steel was identified, with the structure characterized as "dual" and as it approaches of the region close to the ASTM A36 steel, the grains has well delimited boundaries are observed due to the formation of chrome carbides in this region.

The same can be observed for the specimens at a temperature of 650°C emphasizing that the degree of sensitization is so bigger so that most grains can be classified as "ditch". For the same region the specimens heated to 750ºC had the structure formed by "steps" and some grains with "dual" and "ditch", then the sensitization was smaller than others specimens analyzed for the steel, as presented by MAJIDI; STREICHER (1986), also can be observed grains with a latitudinal growth when analyzed with a measure of etch by Vilela, figure 4. According to Tojo (2010) an alternative to decreasing grain growth in the ferritic stainless steel of fused zone (FZ), is the replacement of the welding wire by a tubular weld wire resulting in a grain refining. Comparing hardness of the specimen not exposed to the temperature which was measured an average of 200HV with the specimen exposed to 750ºC which was measured an average of 160HV it is possible to conclude that occurs a hardness reduction due to the effect of the temperature and cooling process who has a behavior of stress relieve.

Figure 4: Temperature effect in Fused Zone (FZ) of the structure formed by AISI439 steel and metal cored wired AISI 430Ti specimens etch with Villela. (A1) Specimen not heated - 50x. (A2) Specimen heated at 650°C for 50 hours - 50x. (A3) Specimen heated at 750°C for 50 hours - 50x.



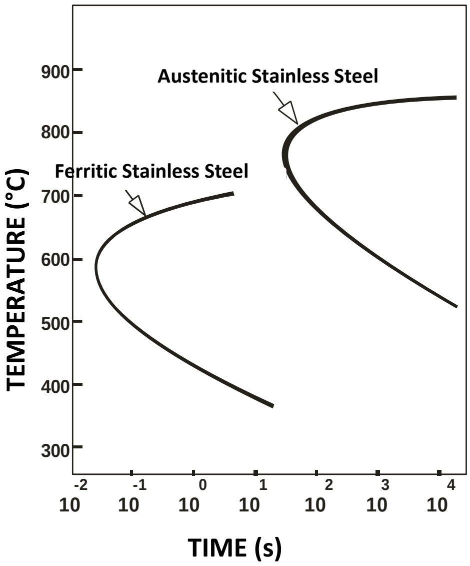
Ref: Own Authorship

In region D of figure 2, as well as in the C region, for the sample without heating it was observed that the closer to the carbon steel, the higher sensitization suffered by the AISI 430 Ti steel, so this phenomenon is connected to a high incidence of carbon present in carbon steel ASTM A36, which propitiate the presence of chromium carbides in the region between grains. The same was observed for the heated sample at a temperature of 650°C, and in the same way as the other regions analyzed, was observed an expressive sensitization, whose structure grain could be classified as ditch. At 750°C, it was also possible to observe the presence of chromium carbides in the bordering region of the heated affected zone (HAZ) and ASTM A36 steel, so that it's only present in this region.

For region D of figure 2, whose illustrated the region of fused zone (FZ) on the border with the heat affected zone (HAZ) of ASTM A36 carbon steel, of the sample without heating, it is possible to observe more sensitization than on region C, in that way almost all the grains can be classified as "ditch" in region D, which according to Ferreira Filho (2010) such behavior is related to the condition suffered by stainless steels stabilized by titanium when these steels are heated at high temperature and then quickly cooled, being susceptible to have sensitization, this phenomenon occurs due to the dissolution of some reprecipitates (in particular TiC) and during the quickly cooling. Hence, the time is insufficient for the carbon to be reincorporated to the precipitates, as a result such carbon may form carbides classified as $Cr_{23}C_6$, undergoing to sensitization. Moreover, for the same region in the structure, it was observed a formation of martensite reticulated in the grain boundaries close to the border of ASTM A36 steel, which is possibly related to the proximity of the steel with high carbon, which according to Ferreira Filho (2007) may be due to the low amount of titanium (Ti) in relation with high percentage of carbon (inadequate stabilization) of the wire. In addition, it was possible to verify the presence of titanium carbonitrides formed in the steel stabilized by titanium (Ti), as evidenced by Madeira (2007).

Therefore, analyzed the effect of time for the two structures it is possible to note that intergranular corrosion was more significant for samples heated to 650 ° C than the sample without heat and the sample heated to 750 ° C. Using the concepts described in literary work of SEEDRICKS (1996), illustrated by figure 5, it is possible to conclude that intergranular corrosion in ferritic stainless steels is more likely to occur for the sample heating by 650° C than 750 ° C, as mentioned by the author this occurs because the carbon and / or nitrogen solubility is higher at 650 ° C than 750 ° C.

Figure 5 - Schematic curves temperature of sensitization versus time showing different results for ferritic and austenitic stainless steels with an equivalent amount of chromium.



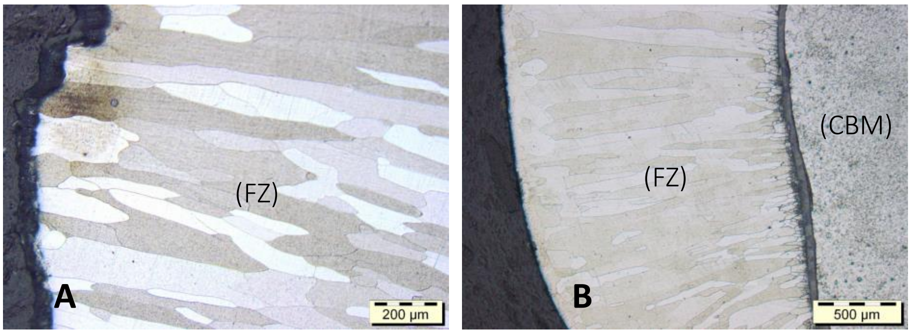
Fonte: SEDRIKS, 1996.

3.2. TIME INTERFERENCE

Analyzing time effect, it was not observed significant changes in grain size and shape, related to the increase of the time in the region of the ferritic stainless steel base metal (BM) and the heated affected zone (HAZ), respectively represented by A and B in Figure 6, in the structure formed by steel AISI 439 and AISI 430 Ti.

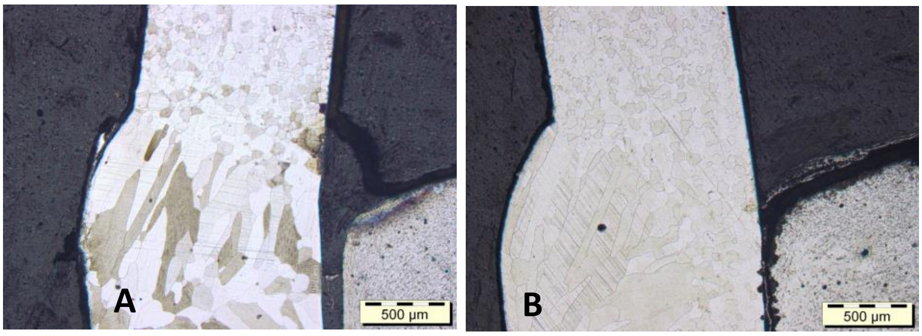
It only was observed a reduction of the average hardness of 190 HV of the specimen heated by 50hs to 150HV of the specimen heated during 100hs. However, in Figure 7, we can observe , in the fused zone (FZ), a lower incidence of sensitization was observed in the heated specimens at 650°C and 100hs compared to specimens heated per 50 hours at the same temperature. One hypothesis could be a growth of the precipitates in grain boundaries and the increase of the time of exposure, there is an increase in the average particle size, but its concentration decreases, thus modifying the continuity of the precipitates, because the more continuous the precipitates are greater the sensitization will be. For the same region, an increase in grain size in the direction of the (CBM-Carbon Base Metal) can be observed, and the location near the (SBM-Stainless base metal) shows an increase of the grain size in the direction of the stainless steel according to figures 8 and 9 below. Hence, as in the SBM region, a hardness reduction was observed, decreasing from 187HV on average regarding the heated sample for 50hs to 160HV regarding the heated sample for 100hs.

Figure 6: Time effect in Fused Zone (FZ) of the structure formed by AISI439 steel and metal cored wired AISI 430Ti specimens etch with Villela. (A) Specimen heated at 650°C for 50 hours - 100x. (B) Specimen heated at 650°C for 100 hours - 50x.



Ref: Own Authorship.

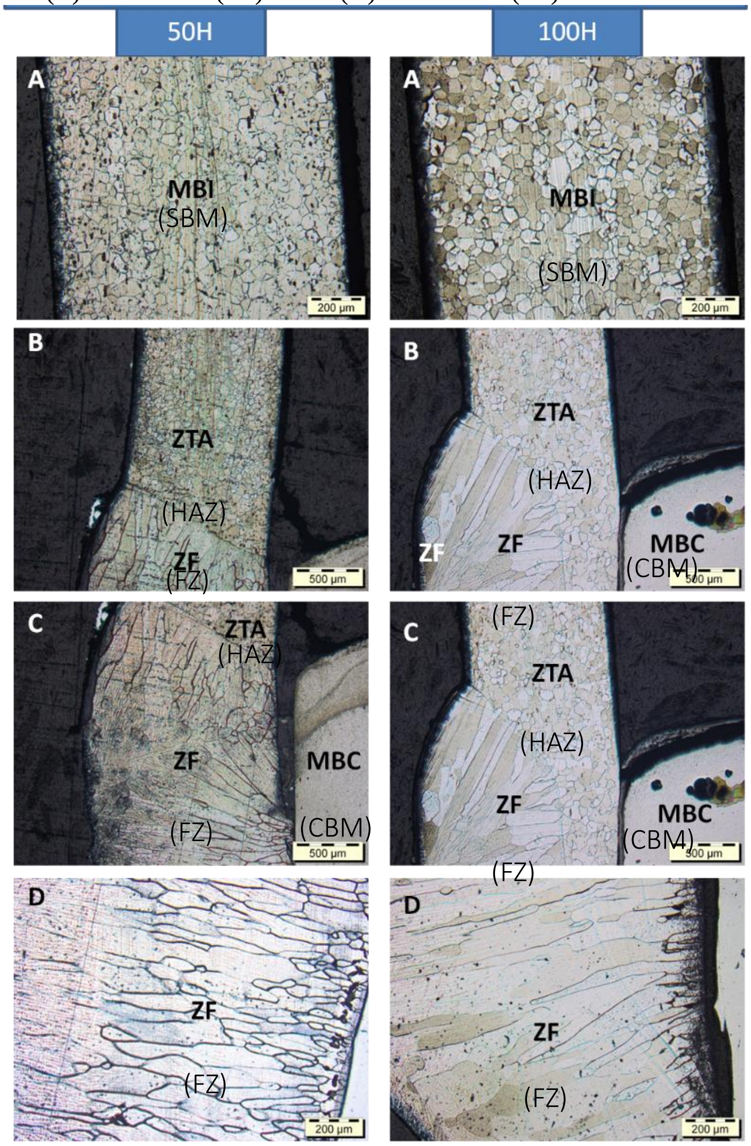
Figure 7: Time effect in the heated affected zone (HAZ) and Fused Zone (FZ) of the structure formed by AISI439 steel and metal cored wired AISI 430Ti specimens etch with Villela. (A) Specimen heated at 650°C for 50 hours - 50x. (B) Specimen heated at 650°C for 100 hours - 50x.



Ref: Own Authorship

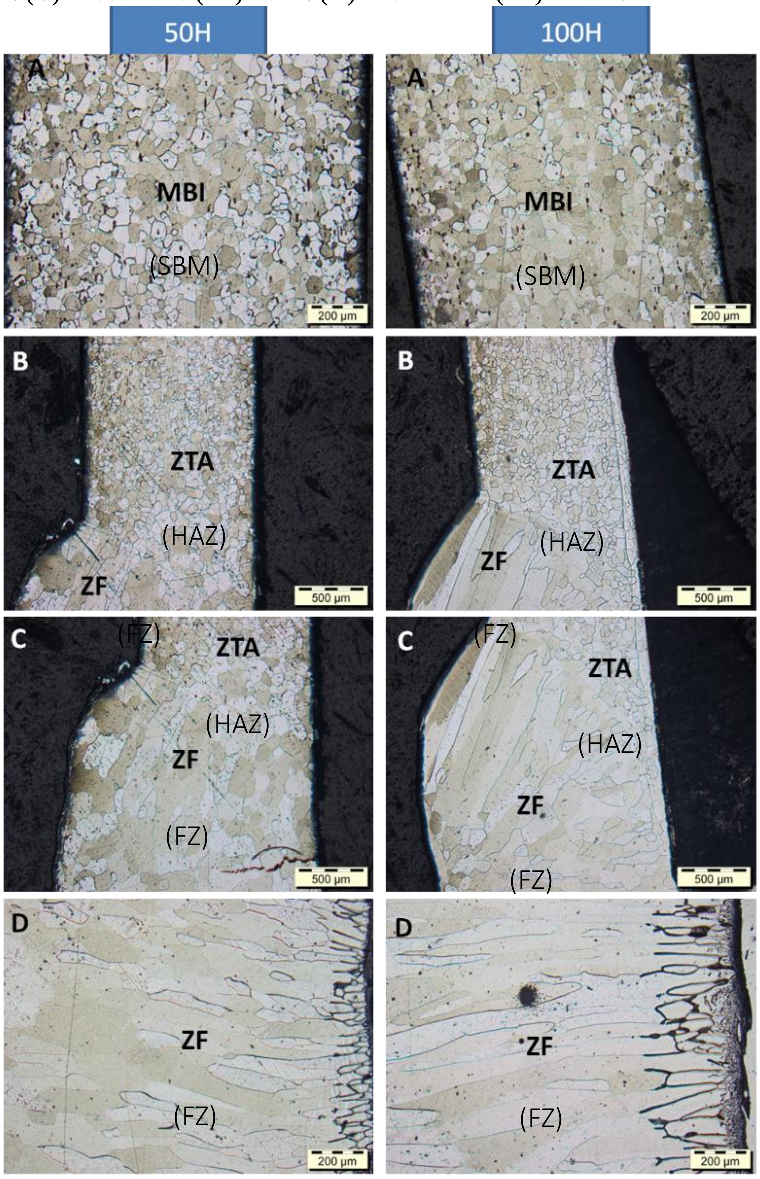
Analyzing figure 8, a prospective conclusion is that the effect of time isn't very significant for sensitization, as the structures of the heated samples of the specimen formed by steel AISI 439 and AISI 430 Ti, heated at 750°C for 50h and 100h had significant no change. The increase in grain size was also not so significant for AISI 439 steel because it has a high concentration of alloying elements increasing the capacity to retain grain increase with the effect of temperature as mentioned by Modenesi (2001).

Figure 8: Time effect in the structure heated at 650°C formed by AISI439 steel and metal cored wired AISI 430Ti specimens etch with oxalic acid 10%. (A): stainless steel base metal (SBM) - 200x. (B) Heat affected zone (HAZ) - 100x. (C) Fused zone (FZ) - 50x. (D) Fused zone (FZ) - 100x.



Ref: Own Authorship

Figure 9: Time effect in the structure heated at 750°C formed by AISI439 steel and metal cored wired AISI 430Ti specimens etch with oxalic acid 10%. (A): stainless steel base metal (BM) - 200x. (B) Heat affected zone (HAZ) - 100x. (C) Fused zone (FZ) - 50x. (D) Fused Zone (FZ) - 100x.



Ref: Own Authorship

4. CONCLUSION

According to the results of this work, it is possible to conclude that the ASTM A36 metal structure showed a hardness decrease with increasing of the temperature caused by grain growth, stress relieve of martensitic in the HAZ region and decarburizing principle of the structure.

Through the metallographic etching with Vilella it was possible to see that the ferritic stainless steel 430 Ti, presented a high hardness in the fused zone (FZ) due to the formation of Titanium carbides, however with the increase of the temperature a decrease of the hardness was observed due the grain growth and the decrease of the the incidence of titanium carbides as the temperature increased, and this phenomenon was verified using the electrolytic etching of 10% oxalic acid. In addition, through the Oxalic etching, corrosion test, it was verified that the sensitization is intensified with temperature increase and time in the region of the fused zone (FZ) near the heated affected zone (HAZ) of ASTM A36 steel, which because it is a region with higher carbon content, occurs carbides precipitation in the structure. It was possible to verify that for the stainless base metal (SBM), heated affected zone (HAZ) and fused zone (FZ) regions there was a higher sensitization to the temperature of 650°C than the temperature of 750°C. It is further added that increasing the time does not interfere with the sensitization of the material.

REFERENCES

ABNT NBR NM ISO6507- **Ensaio de Dureza Vickers Parte 1**: Método de ensaio- **Associação Brasileira de Normas Técnicas**, 2008.

ASTM A763 – 14 - **Standard Practices for Detecting Susceptibility to Intergranular Attack in Ferritic Stainless Steel – American Standards for Testing Materials, 1999.**

CHAWLA, S. L.; GRUPTA. R. K. **Materials Selection for Corrosion Control**. Metals Park, O.H. American Society for Metals. 1995.

DI CUNTO, J. **Estudo da resistência a corrosão de aços inoxidáveis para uso na parte fria dos sistemas de exaustão de veículos**. Universidade de São Paulo. São Paulo, 2005. 105 p.

FERREIRA FILHO, D. **Influência do Gás de Proteção na Soldagem MIG/MAG do Aço Inoxidável Ferrítico com Arames Ferríticos**. 108 f. Dissertação de Mestrado - Universidade Federal De Uberlândia, Uberlândia. 2007.

LLEWELLYN, D.T.; HUDD, R.C. **Steels: Metallurgy and Applications, ButterworthHeinemann**, Linacre House, Jordan Hill, Oxford, 381 p., 2004.

MAJIDI, A. P., STREICHER, M. A., **Four Nondestructive Electrochemical test for detecting sensitization in type 304 and 304L Stainless Steels**. Nuclear Technology, v.75,1986.

MODENESI, P. J. **Soldabilidade dos Aços Inoxidáveis**. Coleção Tecnologia da Soldagem, v.1. Senai, Osasco SP. 2001.

MODENESI P. **Soldagem I - Descontinuidades e Inspeção em juntas soldadas**- Belo Horizonte, 2001.

TOJO, M.; PREMIARC MX-A430M is an Unsurpassed FCW for Cr Stainless Steel Welding - 20-Year Track Records for Welding Automotive Exhaust Systems, **Kobelco Welding Today**, 3. ed. p. 12, 2010.