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SUSCEPTIBILITY TO STRESS CORROSION CRACKING OF STAINLESS STEEL DISSIMILAR JOINT AISI 316 AND AISI 310 AND 2304 DUPLEX STAINLESS STEEL WITH ADDITION OF E2209 METAL.

Leonardo Albergaria Oliveira, leonardoeng1@gmail.com
Edmilson Otoni Correa, ecotoni@unifei.edu.br
Livio de Carvalho Valeriano, liviovaleriano@yahoo.com.br
Thiago Amaro Vicente, thiagofis@hotmail.com

Universidade Federal de Itajubá, Av. BPS, 1303, Pinheirinho, Itajubá, Minas Gerais CEP 37500-903.

Abstract. *In this work we investigated the influence of metal addition duplex 2209 on the susceptibility to stress corrosion cracking by (CST) of welded joints of austenitic stainless steel AISI 310 and AISI 316 stainless steel with duplex UNS S2304, aiming to study the steel austenitic stainless with better resistance to cracking from stress corrosion. For this study, the microstructure of welded joints will be analyzed was used an optical microscope. The mechanical properties of the welded joint with the duplex filler metal were analyzed by tensile and Vickers hardness. To evaluate the susceptibility of welded joints to stress corrosion cracking by, we used the test method under constant load followed by microstructural characterization of the tested specimens CST. The susceptibility to SCC was assessed in terms of time to fracture. The under stress corrosion tests indicate that the HAZ metal base 316 is the most likely region CST.*

Keywords: *Stress corrosion cracking, stainless steel, welded joints*

1. INTRODUCTION

The use of stainless steel in applications whose basic requirement is to have a high resistance to chemical attack by various corrosive media. These steels have numerous applications which are based on their mechanical properties, used at high temperatures or at very low temperatures (MONDONESI PJ, 2001). They are widely used in chemical industries, precision instruments, and in many applications where the use of welding operations is necessary (Chiaverini, V., 2005).

The metal that suffered corrosion, underwent destruction by chemical action or electrochemical means may or may not be associated with mechanical stress. In general, corrosion is a spontaneous process and constantly turning the metallic material resulting in the loss of its mechanical properties. As a result, these materials fail to meet the purposes for which they are intended (Nunes, LP, 2001).

The phenomenon of corrosion under tension (CST) is associated with the presence of a mechanical action combined with a specific corrosive environment and is characterized by the appearance of cracks which promote the fracture of the material, making it one of the most severe degradation mechanisms that influence the useful life of structural components (Fernandes, JC, 2010).

The CST phenomenon has presented several studies in the scientific and technological field, since through the CST tests, it is possible to estimate the lifetime of the equipment and parts in aggressive media predicting risks and appropriately selecting the material for a specific application (FERNANDES, JC, 2010).

The stress corrosion cracking by local corrosion is a process which is characterized by seeding and slow crack propagation in the material under the simultaneous action of tensile stress and a specific corrosive environment (Bauernfeind et al., 2004). In general, the formation of corrosion under stress cracking occurs in tension values below the yield stress of the material and typically below the design voltage and a structural component fatigue limit (Boven, et al., 2007).

Due to this, resistance to stress corrosion cracking is one of the most important requirements to be considered when performing welding austenitic stainless steel. The stress corrosion cracking, in turn, is strongly influenced by undesirable microstructural changes occurring during welding or during post-weld heat treatment of components (Sui et al., 1996). According (Linton, 2004), the presence of the sigma phase, and chi phase / or chromium nitrides in welded joints are responsible for the decrease in resistance to pitting and stress corrosion resistance of duplex steels.

Therefore, this paper aims to investigate the influence of the chemical composition of the metal addition on the microstructure and resistance to stress corrosion cracking (CST) stainless steel dissimilar joints 310 and 316 austenitic and duplex stainless steel 2304 in medium containing chloride. The correct selection of the filler metal can constitute an efficient practice to eliminate or minimize the occurrence of CST when performing dissimilar welds during fabrication and equipment repair of drilling for oil, petrochemical and nuclear.

2. MATERIALS AND METHODS

To evaluate the susceptibility to stress corrosion of dissimilar steel welded joints 310 and 316 austenitic and duplex 2304 for chlorides, couplings were performed by the conventional MIG welding process for filling stainless steel AISI 310 and AISI plates of dimensions 316 x 65 300 mm x 4 mm chamfered in V. The metal used was added solid wire of 1.2 mm diameter of stainless steel 2209 duplex. Table (1) shows the chemical composition of the base metal and filler metal used.

Table 1. Chemical composition (% by weight) of metal added and base metal

	C	**Mn**	**Si**	**Cr**	**Ni**	**Mo**	**P**	**S**	**N**
AISI 310	0,250	2,0	1,5	26,0	19,0		0,045	0,03	-
AISI 316	0,032	1,367	0,49	16,20	9,20	1,99	-	-	-
UNS 32304	0,020	1,356	-	22,23	3,61	0,31	-	-	1090 (ppm)
ER2209	0,030	1,700	0,50	22,50	8,50	3,30	-	-	-

The welding parameters for the addition of metal, were selected values within the range usually employed by the manufacturer in welding components subject to stress corrosion cracking. Table (2) shows the welding parameters adopted.

Table 2. Main welding parameters

Voltage (Volts)	Current (A)	Welding Speed (m/min)	Welding Speed (m/min)	Shield Gas
19	120	0,26	4	Argon 100%

It was found assay Vickers microhardness measurements with 10 kgf load on each welded test bodies. The measurements were performed at a distance of 2 mm from the top face of the welded surface in its cross section. A total of 20 measurements was performed on each sample value of the distance between the two lines was measured on a horizontal 1 mm and, in the vicinity of the fusion line, they were performed at 0.5 mm distance.

The corrosion tests under stress were performed on the device with loading type load (CC) constant shown in Fig. (1) using tensile test specimens without notch cross welded and longitudinally to its axis.

In the manufacture of the specimens were used standards of standardized procedures by ASTM G58 and ASTM E8, From the welded joints of transverse mode was taken 10 specimens. Figure (1) observed the schematic design and dimensions of the specimens. CST test bench consisted of a load application device by a dead weight device, which gave good uniformity and repeatability load. The specimen was introduced into a glass bowl to keep it submerged in the test solution. The bowl in turn, was installed in a reflux condenser. The etching solution used was an aqueous solution of magnesium chloride (43%) according to ASTM G36. The working temperature in the tests was 140 ± 2 ° C, equivalent to the boiling temperature of a magnesium chloride solution with concentration of 43%. Figure 2 shows the bench used for corrosion tests under stress.

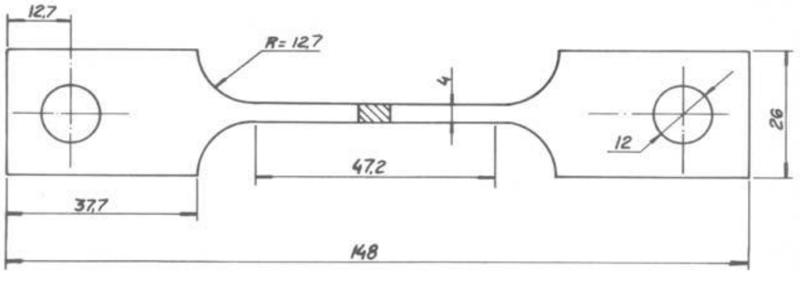

Figure 1. Schematic drawing of the specimen and dimensions of CST Body of Proof.

Figure 2. Device for CST constant load test.

An axially tension to the specimen axis was 250 MPa, corresponding to approximately 80% of the 0.2% yield strength of the already welded specimen was applied. The samples after the test were fractured, this was removed a sample of 20 mm long to carry out metallographic testing via optical microscopy.

The parameter used to assess the susceptibility to SCC in the experiment was the time taken for the occurrence of breakage of the specimens.

3. RESULTS AND DISCUSSION

3.1. Hardness of welded joints

The standard NACE MR0175 (Logan, 1990) was used, a maximum hardness is 250 HV to austenitic steels for use in oil equipment, with the use of this standard to avoid a stress corrosion cracking in media containing H2S.

There is no correlation between the hardness of the welded joints of dissimilar austenitic stainless steel and its susceptibility to SCC in chloride has been reported, but notes the use of a maximum of 250 HV. The Figures (3) and Figure (4) shows the Vickers hardness chart of welds performed. The hardnesses were measured horizontally across the cross section of the samples and 2 mm from the surface. The maximum hardness value found was 221 HV; making this acceptable as welded joints, according to the criteria adopted by NACE.

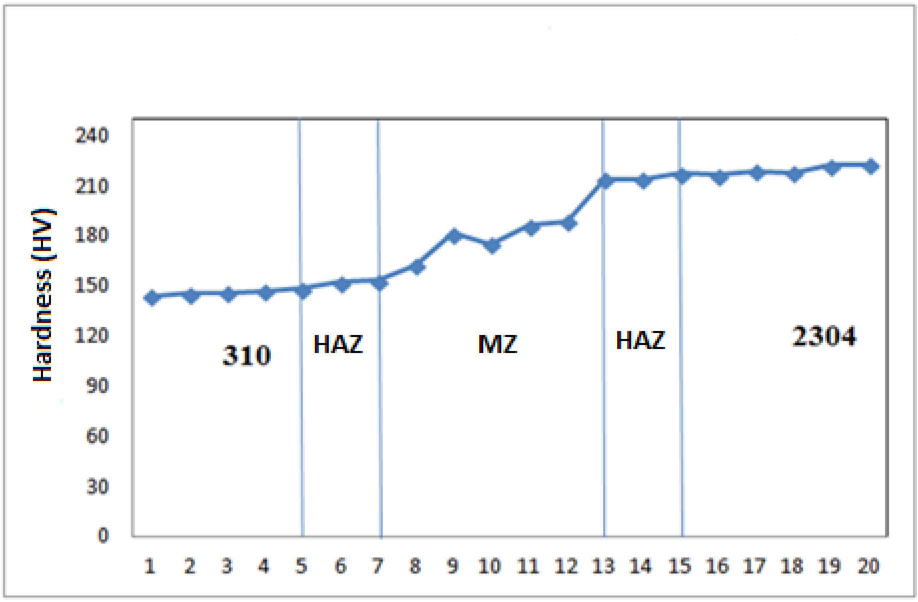

Figure 3. Average Graph of hardness of welded joints with the addition of metal and E2209 Base metal AISI310.

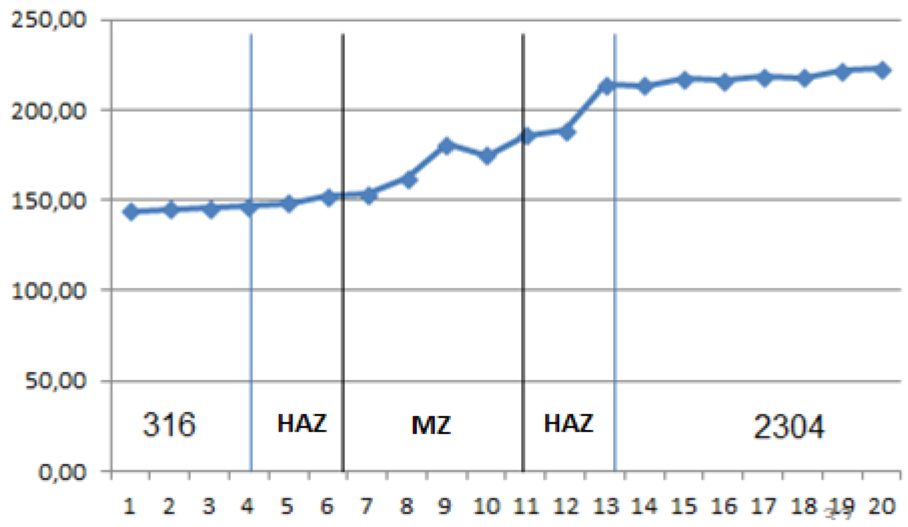

Figure 4. Graph of the average hardness of welded joints with the addition of metal and E2209 Base metal AISI316.

3.2. Corrosion Under Voltage (CST)

The parameter used to evaluate the susceptibility to cracking by stress corrosion of dissimilar joints of stainless steel 310 and 316 and the duplex steel in 2304, it was time to occurrence of complete fracture of the body of the test piece. Table (3) shows the average values of the test temperature and the time for adding the two metals.

Table 3. Results of CST tests

Base metal	T (°C)	pH	Tensile (% σes)	Time Average Crack (min)
310	140	≈ 4,0	80	212,9
316	141	≈ 4,1	81	84,3

The results showed that:

a) The crack nucleates at ZF through the delta ferrite network and propagates to the steel ZTA ZTA duplex 2304. In this crack propagates faster due to the presence of σ phase in the base metal AISI 310 austenitic joint.

b) Nucleation and propagation of cracks in the HAZ of the steel duplex 2304 due to the presence of σ phase in this region. The σ phase is a hard and brittle phase, which decreases the toughness and corrosion resistance of this region which makes it more susceptible to cracking CST base metal gasket austenitic AISI 310.

The amount of nickel (Ni) in the weld metal is significantly greater than the base metal, and 2304 as is known, acts as nickel austenite stabilizer which reduces the possibility of σ phase formation. The presence of a low volume fraction of σ phase may be due to little or no migration of chromium (Cr) for HAZ duplex metal base 2304 or a possible migration of nickel (Ni) in this region, the base metal gasket AISI 310 austenitic.

Fractures in the specimens occurred in the HAZ and in the connection zone (HAZ / ZF) on the base metal side duplex 2304, the base metal gasket austenitic AISI 310, and in the connection zone (HAZ / ZF) on the metal side base 316, which can be assigned to this region due to embrittlement of the grain growth phenomenon, and the possible presence of σ phase.

Macroscopic analysis of the fractured region showed the presence of two distinct regions: one from the corrosive process and another coming from the mechanical fracture, a result of increased tension due to the reduced area of the specimens.

The region arising from the mechanical fracture also showed aspect of brittle fracture. The fractures occurred throughout the length of the specimen, and all regions showed cracks occurrences.

Tests have revealed that duplex steels and 316 are susceptible to stress corrosion cracking in the applied environment. However, different welded joints exhibited lower susceptibility than the starting materials (LABANOWSK, 2007).

The 316 stainless steel has a chemical composition similar to that of 304 stainless steel; and also presents metastable austenitic structure, and a small fraction of delta ferrite, and has a large amount of molybdenum, which increases the resistance to pitting corrosion.

Fractures of the test glasses predominantly occur in the HAZ in the austenitic metal base side 316, which can be attributed to embrittlement from this region due to the grain growth phenomenon, and the presence of delta ferrite in continuous networks in the metal in the molten zone of E316L weld. There was also a possible formation of sigma phase volumetric fraction

3.3- Microstructural analysis after the CST test.

3.3.1 Board welded to the base metal AISI 310.

The microstructural evaluations along with the results of the CST tests indicate that the HAZ and the connection zone (HAZ / ZF) is more susceptible to cracking by CST region. In general, most of the samples showed cracks in this region, which led to fracture of the specimens as shown in Figure 4.

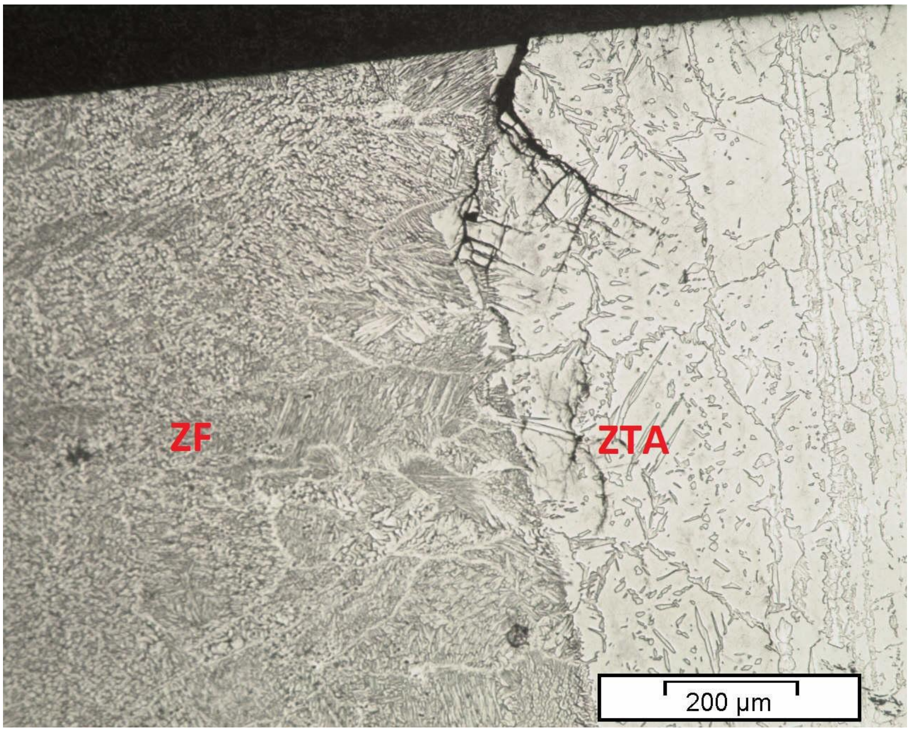

Figure 4 of stress corrosion cracks in the bonding zone of the welded joint with the base metal 310. electrolyte Attack: Oxalic Acid

3.3.2 Welded Joints with base metal AISI 316.

Microstructural evaluation of the soldered joint with weld metal 2209 indicates that the HAZ metal base 316 is the most likely region CST. According to the literature, this austenitic stainless steel such characteristic features, which may have taken more fractures occur in this region.

In Figure 5 one can notice a crack that probably due to sigma phase and grain growth in the HAZ, it may be noted that the region of the HAZ is subject to precipitation of carbides and carbonitrides, which can result in compositional heterogeneity in region of the grain boundaries, making these anode areas relative to the rest of the grain by accelerating therefore the development of transgranular cracks (Barbosa, 1995) and weakening region, which causing a fracture.

It notes that the test temperature was critical temperature, second (FERNANDES, 2010), to the corrosion of stainless steel 316 and the highest to happen CST. At high temperatures, the grain of the breast becomes more resistant to crack propagation region, and the grain boundary less resistant region and preferred to crack propagation. As observed cracks are propagated through the grain sinus (transgranularmente) is likely due to high corrosion rates at these temperatures, the metal dissolution at the crack tip was faster than the diffusion of hydrogen into the structure, CST becoming the predominant mechanism.

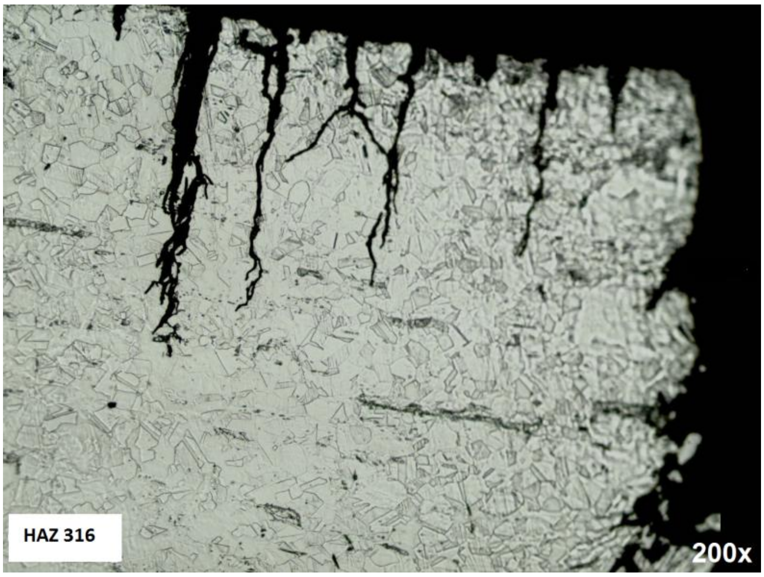

Figure 5. Photograph of the specimen fracture 316 + 2209 + 2304.

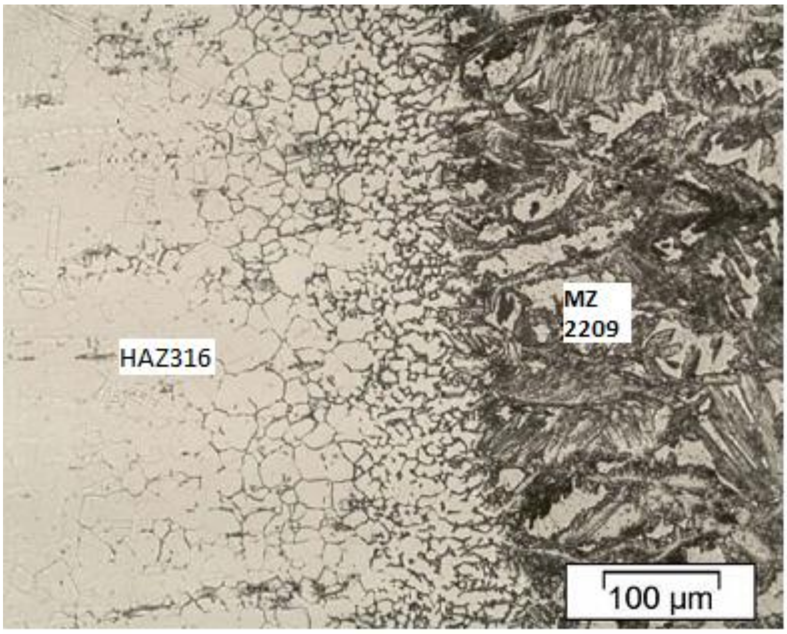

Figure 6. Microstructure of the HAZ. Steel side 316. It is noted was the formation of delta ferrite.

Microstructural evaluation of the soldered joint with weld metal 2209 indicates that the HAZ metal base 316 is the most likely region CST because of fractures have occurred in this region Figure 7 and Table 4 show the EDS analysis results of the dark precipitates observed in Figure 6 and these strongly indicate that it is the sigma phase, because this phase is rich in Fe, Cr and Mo. Importantly, the duplex steel metal addition in 2209, the chemical composition of both the base metal 316 and especially the 2209 addition of metal favor the formation of delta ferrite and sigma phase in the HAZ metal base 316, as shown in Figures. This can be attributed to higher levels of chromium and molybdenum steel in 2209 compared to the levels observed in the stainless steel base metal 316. Because the dilution of the weld in the order of 25% of MIG and subsequent cooling of the solder, chrome piece and the addition of molybdenum metal tend to migrate to the metal base 316 HAZ since the concentration gradient of these elements is fairly high. According to the literature, these factors strongly influence the formation of delta ferrite and sigma phase. Incidentally, as a rule, the sigma phase arises from the delta ferrite, which concentrates the elements Cr and Mo (Voronenko, 1997; Jiang et al, 2003).

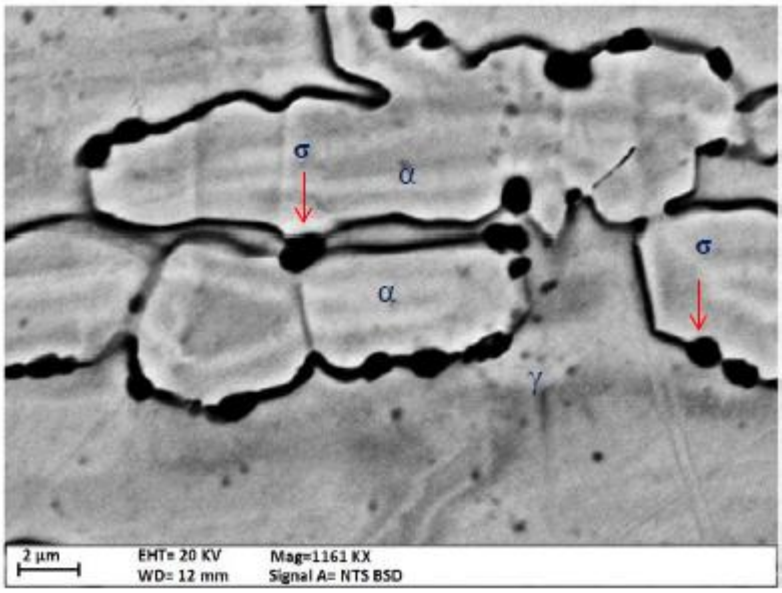

Figure 7. Micrographs showing precipitates in HAZ probably phase Sigma. Steel side 316.

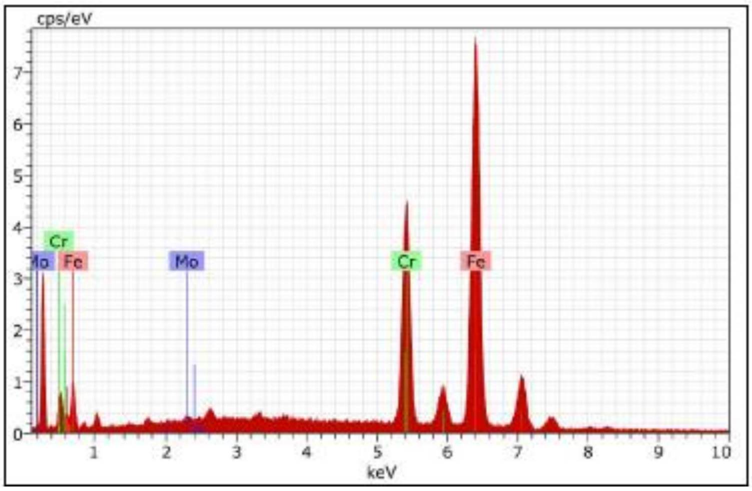

Figure 8. Analysis of the SDS stage shown in Figure 11.

Table 5. Results of the levels of the chemical elements of the EDS

Elemento(%peso)		
Fe	Cr	Mo
75,18± 1,89	24,27 ± 0,64	0,35±0,05

4. CONCLUSIONS

From the analyzes and observations about the influence of filler metal in susceptibility to stress corrosion cracking joints dissimilar welded stainless steels 310, 316 and duplex stainless steel in 2304 and it can be concluded that:

- From the CST tests magnesium chloride aqueous solutions was evident that all the specimens clenched by CST, especially for next loading levels of the joint yield strength.

- The hardness values found in the welded joints showed a good correlation with the tensile tests and CST. All found hardness values were below the limit proposed by the standard NACE MR015-2001, which establishes a maximum hardness limit of 250HV.

- The region of the dissimilar joint which was more susceptible to CST was austenitic stainless steel HAZ 316. This is because these steels form the molten zone and the HAZ semi-continuous networks delta ferrite that facilitate the propagation of cracks CST by grain boundaries of ferrite.

- The dissimilar joint using stainless steel base metal austenitic 310 proved to be more resistant than the CST dissimilar joint using austenitic stainless steel 316. This is due to the simultaneous presence of delta ferrite and sigma phase networks in the metal base 316 ZTA when using a filler metal of duplex stainless steel.

5. ACKNOWLEDGEMENTS

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