MECHANICAL AND MICROSTRUTURAL CHARACTERIZATION OF WELDED JOINTS OF FERRITIC STAILESS STEEL AISI 444[1]

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Abstract

The objective of this study was to investigate the influence of the filler metal on the microstructure and mechanical properties of ferritic stainless steel AISI 444 welded using two types of filler metal of austenitic stainless steel. Microstructure examinations showed that, in both welded joints, occurred grain growth in HAZ. The results also showed that the fusion zone of the weld joints using E309L filler metal presented a discontinuous network of delta ferrite unlike the fusion zone of the weld joint using E316L. Tensile tests showed that the failures of specimens always occurred in the HAZ and that the weldments using E316L filler metal presented tensile strength limit lower than that of the weldment using E309L filler metal. In the fusion zone of the weldments using E316L filler metal, it was found higher hardness values than those found in the fusion zone of the E309L filler metal.
Keywords: Welded joints; Stainless steel AISI 444; Microstructure.

CARACTERIZAÇÃO MECÂNICA E MICROESTRUTURAL DE JUNTAS SOLDADAS DO AÇO INOXIDÁVEL AISI 444

Resumo

O objetivo deste trabalho foi investigar a influência metal de adição sobre a microestrutura e as propriedades mecânicas do aço inoxidável ferrítico AISI 444 soldados com dois tipos de metal de adição de aço inoxidável austenítico. As analises microestruturais mostraram que em ambas juntas soldadas ocorreu crescimento do tamanho de grão na ZTA. Os resultados mostraram também que a ZF com o metal de adição E309L apresentou uma rede de ferrita delta descontínua, ao contrário da zona fundida com o metal de adição E316L. Os testes de tração mecânica apresentaram que as fraturas dos CPs ocorreram sempre na ZTA e que a junta soldada com o metal de adição E316L apresentou um limite de escoamento inferior à junta soldada com o metal de adição E309L. Na ZF com o metal de adição E316L, foram encontrados valores de dureza maiores que os valores encontrados na ZF com o metal de adição E309L.
Palavras-chave: Juntas soldadas; Aço inoxidável AISI 444; Microestrutura.

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1 INTRODUCTION

Stainless steels are defined as alloys Fe-Cr containing a minimum of 11% Cr. Its main property is the resistance to corrosion, where it is due to a thin film that forms on the surface of the material called passive film from the interaction of chromium of alloy with oxygen in the atmosphere to form a layer of chromium oxide (Cr_2O_3).[1] These steels are divided into different classes that vary according to the chemical elements present in them, such these elements are responsible for the stabilization of the ferritic and austenitic microstructure, or both. Some stainless steels can have in its composition an amount of up to 30% Cr, and other elements that can be added such as: Ni, N, Mo, Ti, Nb, Al, Cu.[2] According to ASM e Moore,[3,4] the stainless steels can be divided into five families: four are based on the crystallographic characteristics / microstructure of the alloy: ferritic, martensitic, austenitic, duplex (austenite + ferrite) and the 5th family, alloys hardened by precipitation, is based on the type of heat treatment used, instead of the microstructure.

Austenitic stainless steels are the largest family of stainless steels in terms of number of leagues and use. Its basic composition is summarized Fe-Cr-Ni and the name assigned to them due to their austenitic structure at room temperature, that is, face-centered cubic (FCC). Such as the ferritic stainless steels, these can not be hardened by heat treatment. However, their similarities end here. The austenitic alloys are non-magnetic, offer optimal conditions for stamping and welding, and are especially susceptible to cracking by stress corrosion cracking.[1] In the case of ferritic stainless steels, they have a composition mainly of Fe-Cr with ferritic crystalline structure, or corps-centered cubic (CCC). The chromium content is usually in the range of 11 to 30%. Their use depends on the general content of chromium. Some types may contain Mo, Si, Al, Ti and Nb to confer particular characteristics. These alloys are magnetic, not have good weldability and as stated are not hardened by heat treatment.[1,5] The alloy prototype third-generation of ferritic stainless steels is the type AISI 444 (18Cr-2Mo), which this contains higher content of molybdenum ferritic 400 series and is also stabilized.

According to Carvalho et. al.[6] there are many properties of ferritic stainless steel AISI 444 superior to austenitic stainless steels, such as its ability to be produced in the form of tube and/or by cold rolling with low roughness, high resistance to corrosion, considerable heat exchange capacity, excellent resistance to fatigue and stress corrosion cracking, good hardness and considerable resistance mechanic.

Studies have shown its effectiveness in applications for the biofuel industry as heat exchangers, evaporators, dryers, crystallizers, fermenting, storage tanks, as well as in the petrochemical sector in reversing internal equipments, towers distillation of petroleum, the structural components of machines and structures, applications to high temperatures such as in exhaust systems of cars, tanks term and solar heaters.[7,8,9] In many applications of stainless steels is necessary to use soldering operations. Welding is the main industrial process for joining metals. Procedures for welding and related processes are widely used in the manufacture of parts, recovery of parts of the industry (worn parts) and for applying coatings of special features, often stainless steel, on metal surfaces. This wide use is due to several factors and, in particular, its relative simplicity of operation.[10]

Within the area of Materials Engineering, says the study of techniques and consumables for the welding of ferritic stainless steels with austenitic stainless steels. This welding dissimilar aims to combine the high resistance to stress corrosion cracking and good thermal conductivity of ferritic stainless steels (which generally have limited weld-ability), with the good weld-ability presented by austenitic stainless steel (but which are generally susceptible to stress corrosion cracking).[11] In this context, this work was motivated by the great need that the Petrobras refineries and other industrial sectors have to have procedures in welding fabrication and repair leading to the award of welded joints with good properties such as low susceptibility to corrosion and good properties mechanical. So even tried to characterize the mechanical and microstructure welded joints of ferritic stainless steel AISI 444 with the addition of metals to austenitic stainless steels E309L and E316L.

2 EXPERIMENTAL PROCEDURE

Manual MIG (Metal Inert Gas) welding was performed on “V” notched AISI 444 ferritic stainless steel base plates of dimensions 140 mm x 70 mm x 3 mm using two different types of filler metals (AWS E309L and E316L). The chemical composition of the weld metal and the base metal are given in Table 1.

Table 1. Chemical composition of base metal and weld metal deposits[9]

Stainless Steel	Composition (wt%)							
	C	Cr	Mo	Ni	Mn	Si	P	Ti+Nb
AISI 444	0,025	17,50	1,75	1,00	1,00	0,030	0,040	0,80
E316L	0,02	17,5	2,8	12,2	1,7	1,0	0,02	-
E309L	0,03	23,05	0,1	13,0	1,5	0,75	-	-

Table 2. Welding parameters used for both metal addition

Welding Parameters	
Current (A)	125,0
Voltage (V)	20,0
Heat Input (kJ/cm)	5,0
Travel Speed (cm/min)	30,0
Speed Wire Feed (m/min)	4,0
Gas Protection	C25 (Ar 25% CO_2)

All welds were made in the flat position by the same welder. The plates were rigidly fixed on a bench to avoid excessive warping of them due to their small thickness. After welding, each weld joint was removed two strips with dimensions (141 x 22 mm) were machined in which obtaining samples of traction to ASTM G58 and ASTM E8 Figure 1. Specimens were sectioned transverse to the surface and Vickers hardness tests were performed. The hardness measurements were taken on a distance of 2 mm from the welded surface. A profile of one extremity to another of specimen was drew, starting in base metal (BM), passing through the heat affected zone (HAZ), fusion zone (FZ), until the other end the of the metal base. Was obtained 17 marks in each sample, as illustrated in Figure 2.

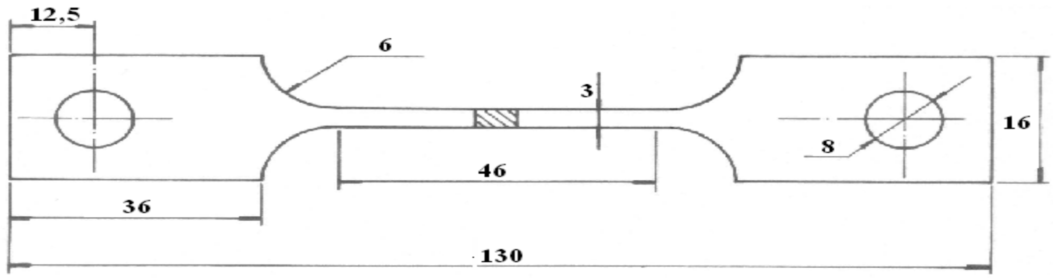

Figure 1. Dimensions of the specimens in millimeters.

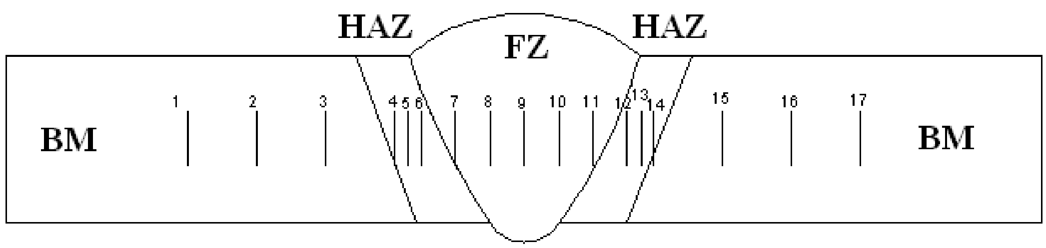

Figure 2. Profile for measurement of Vickers hardness.

The microscopic analysis have been realized by means of a microscopic optic coupled to a microcomputer (image analyzer) and Scanning Electron Microscopy (SEM).

3 RESULTS AND DISCUSSION

3.1 Microstructure Characterization

Figure 3 shows the microstructure of welded joints with weld metal E316L and E309L, respectively. In both figures, one can clearly observe the grain growth in ZTA.

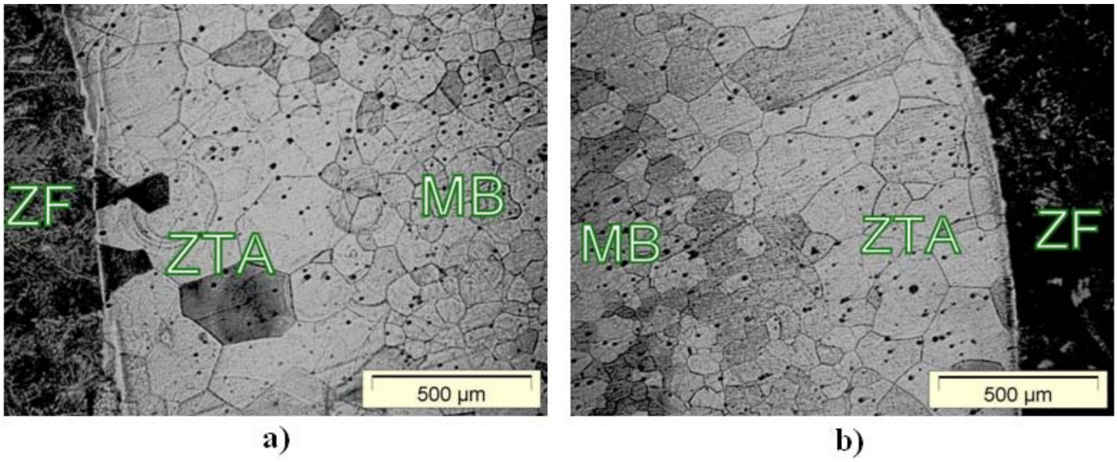

Figure 3. Microstructure of welded joint with: a) E316L and b) E309L – Etching: Aqua Regis.

According to Oliveira and Faria,[12] the most widely used to control the grain growth is through the addition of stabilizers (Ti, Nb) and control of welding energy, so that the lower the energy of welding is the lowest growth grain. Measurements of grain size in HAZ performed showed that the grain growth was virtually identical in both cases. This indicates that the dilution and cooling rate of the two welds were not influenced by the

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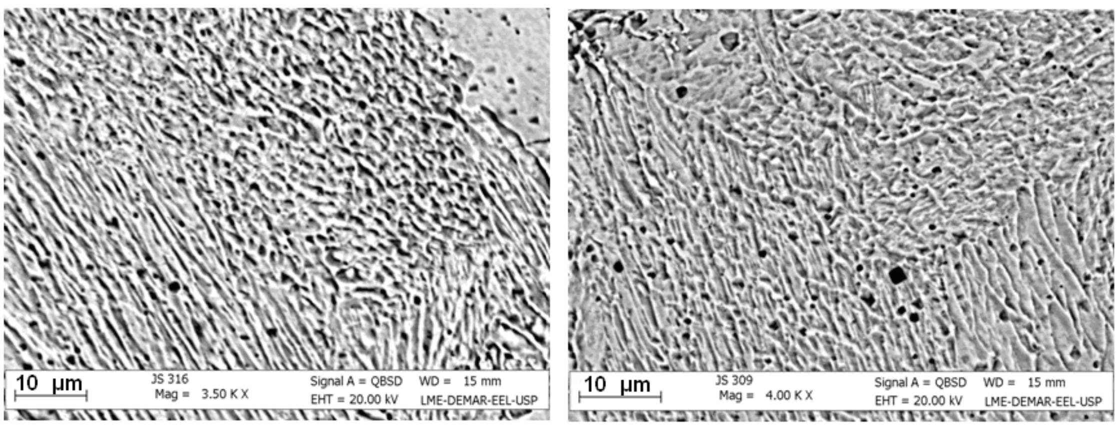
difference in chemical composition between the fillers metals, being more dependent on energy welding (5.0 KJ / cm for both).

Figures 4a and 4b present microstructures of fusion zone (FZ) of welded joints with weld metal E316L and E309L, respectively. It can be observed in FZ with E316L filler metal (Figure 4a) that the delta ferrite (dark phase) is present in greater quantity and for a network continuous. Furthermore, the ZF with E309L weld metal (Figure 4b), the delta ferrite is present in smaller quantities and more discontinuous.

The presence of delta ferrite in smaller quantities and discontinuously in E309L filler metal can be attributed to the increased presence of Ni (austenite stabilizer) in the composition of weld metal, which reduces the formation of delta ferrite in the austenite-ferrite interface at the end of solidification. On the other hand, the presence of higher amount of delta ferrite and has been relatively steady in the 316L weld metal can be attributed to the increased presence of Mo (strong ferrite stabilizer) in the composition of weld metal, which increases the formation of ferrite delta in ferrite-austenite interface at the end of solidification.



a) b)

Figure 4. Microstructure of FZ with: a) E316L and b) E309L – Etching: Sodium Thiosulphate. MEV.

It should be noted that when the delta ferrite is formed continuously since the solidification of the weld metal, it contributes more effectively to the crack propagation CST in ferritic grain boundary. Therefore, comparing the microstructures of the two areas merged, it is observed that the E309L filler metal has a microstructure less susceptible to the corrosion for the E316L filler metal as a network of delta ferrite discontinuous difficult to crack propagation along the grain boundaries.

3.2 Tensile Tests

There were three tensile tests for each different electrode (E316L and E309L). The tests showed that the welded joints with weld metal E316L behaved more fragile when the welded joints with the electrode E309L. Figure 5 (a and b) shows the curves (averages of three tests) of stress (MPa) versus deformation (mm) during the tensile tests. Fracture of the specimens for both weld occurred in the heat affected zone (HAZ), which can be attributed to grain growth in this region and the phenomenon of sensitization. Through the graphs in Figure 5 (a and b) can be seen that for the welded joints with weld metal E316L, the yield stress and maximum tensile strength proved considerably lower for the welded joints with weld metal E309L, the which shows the greatest weakness of welded joints with weld metal E316L. Figure 6b has obtained microfractography SEM two specimens tested for mechanical tensile.

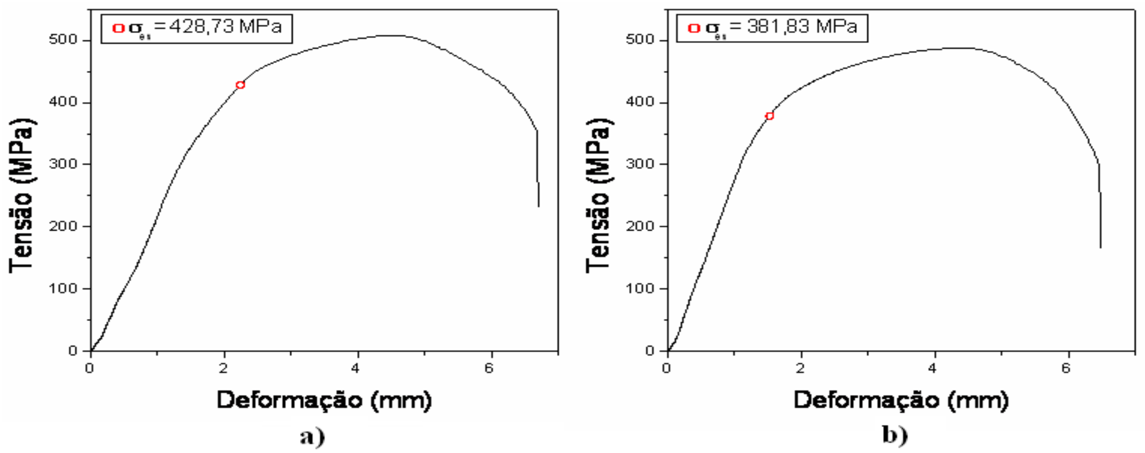


Figure 5. Tensile tests performed in welded joint with the filler metal: a) E309L and b) E316L.

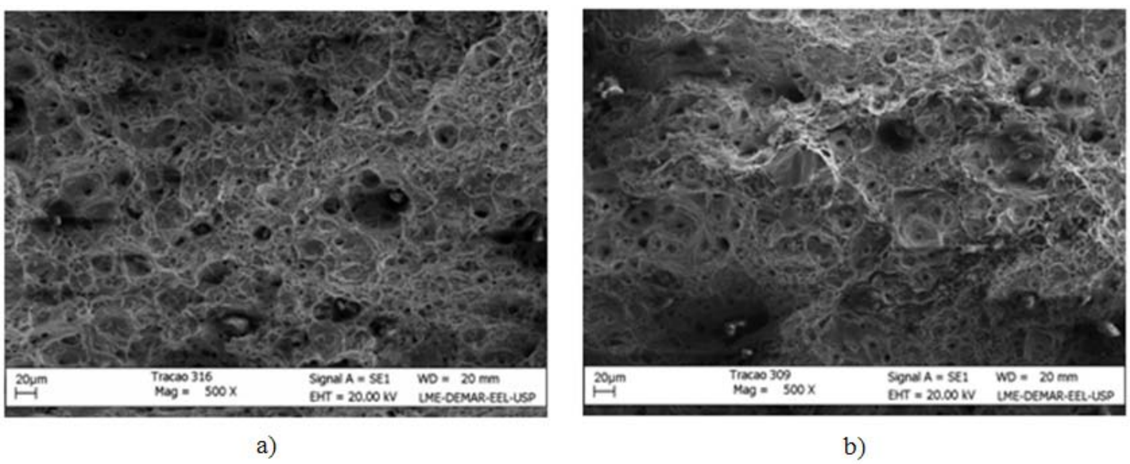


Figure 6. Microfratografias of specimes tested by tensile: a) Filler metal E316L b) Filler metal E309L. Magnification: 500x. SEM.

Can observe the emergence of Dimples on both samples (weld with E316L and E309L), highlighting the appearance of ductile fracture. As the failures during the tensile tests occurred in the HAZ / BM (AISI 444), it was expected the ductile aspect, because it is a ferritic stainless steel which normally has this type of fracture. According to Pinto,[11] it is likely that the origin of this weakness may be related to the filler metal used because it is materials that have their compositions in a relatively high content of silicon (0.75 to 1.0) which, although improving the fluidity of the weld metal during the welding operation, may be promoting, the effect of evil, the fragility of the material in the welded region. A SEM analysis also revealed that, in the CPs tested by mechanical traction, there was some precipitation of particles in the material. Figure 7 shows one of these precipitates where their respective chemical analysis obtained with EDS, is shown in Figure 8.

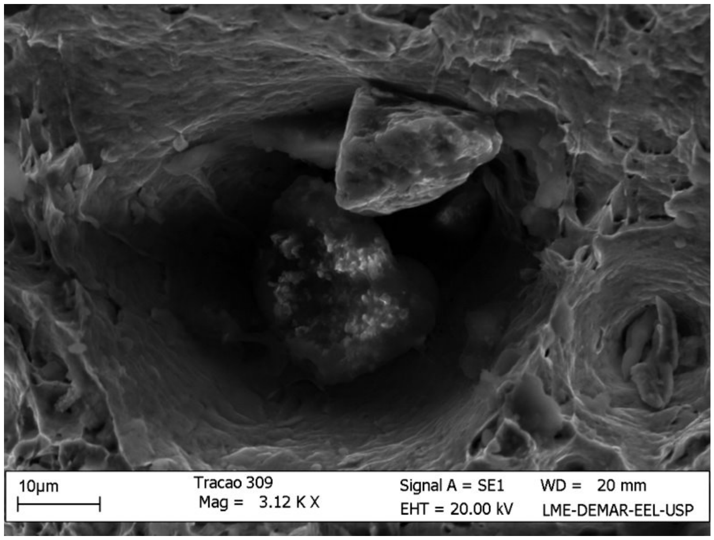


Figure 7. Precipitate present in CP tested by tensile, filler metal: E309L. Magnification: 3120x. SEM.

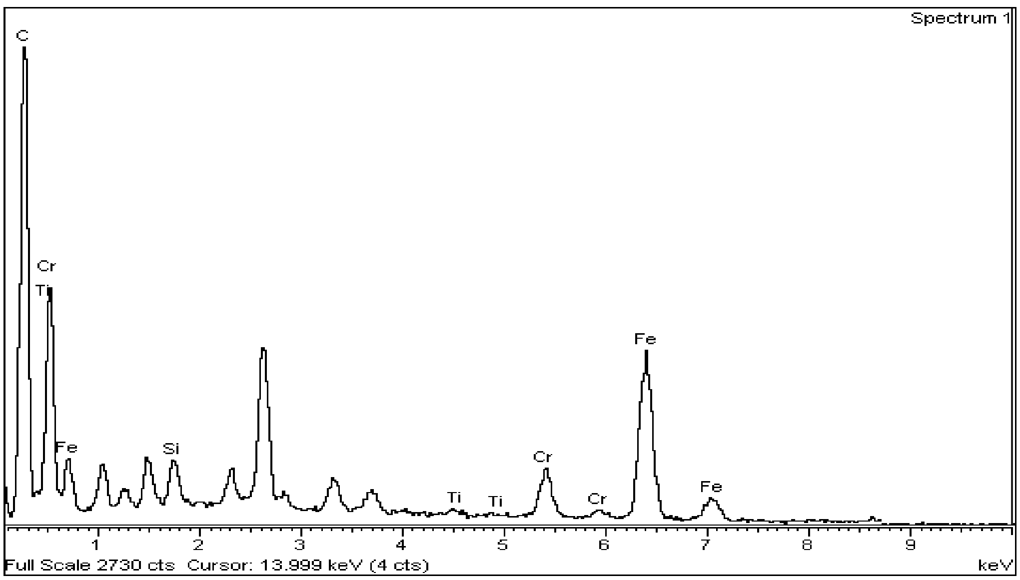


Figure 8. SEM - EDS precipitate present in CP tested by tensile, Metal Added: E309L.

3.3 Weldments Hardness

Figure 9 displays the graph on the Vickers hardness tests over the specimens. The red curve represents the tests in the weld with the weld metal E316L and black curve represents the tests in the weld with the weld metal E309L. It is observed a certain similarity between the curves, in which both begin at close to 165 HV_5, increase to the point 4 to values around 180 HV_5 subsequently, suffer a slight decrease to the point 6 and a sudden increase in points 8 and 9 reaching values near 220 HV5. After reaching the maximum hardness, the curves of the graphs decreases to the point 17 and returned to levels around 165 HV5. These variations in hardness are totally related to changes in the microstructure of welded joints. Values of about 165 HV_5 refer to the BM, values around 180 HV5 refer to the HAZ and values above 190 HV_5 refer to the FZ.

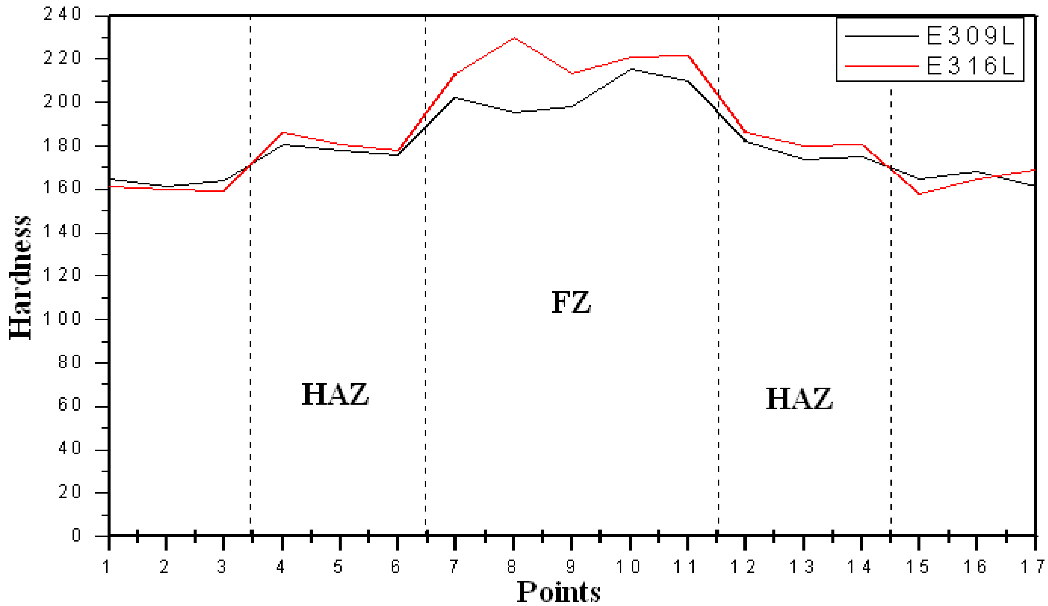


Figure 9. Profile hardness ferritic stainless steel AISI 444 welded to the metal addition E309L and E316L.

The hardness values found in the MB are virtually identical in the two samples. This could not be different because it is the same base metal (AISI 444) for all specimens, since the area known as the MB does not suffer a kind of change in its microstructure and chemical composition during the welding process. Occurs in HAZ grain growth, which may be seen in Figure 3. The grain growth is responsible for an increase in the profile of hardness of metals, which can be observed in points 4, 5, 6, 12, 13 and 14 of the graph in Figure 9. The fact that the hardness in the HAZ for the two filler metals are virtually the same whether using the same welding parameters and the same metal base for the two samples.

In FZ we found the highest values of hardness, which shows that this is the most fragile region of the weld. Despite these hardness values are higher than the values found in the BM and HAZ in both samples, they differ somewhat from each other. In the weldments with filler metal E309L, the hardness FZ average is around 203 HV, while in the weldments with filler metal E316L hardness FZ average is 220 HV. From these data it is observed that using E316L filler metal, it will generate a FZ weaker compared with the E309L. This is due mainly to difference in chemical composition that can be seen in Table 1. Note that the chemical compositions are similar, except for amounts of chromium and molybdenum, where these two components have properties that increase the hardness of steel.

In the chemical composition of weld metal E309L has 23.05% Cr and 0.1% Mo by weight, while in the E316L filler metal has been 17.5% Cr and 2.8% molybdenum. As the hardening effect of molybdenum is considerably greater than the hardening effect of Cr, FZ of the weld with the weld metal E316L was more fragile than the FZ of the weld with the weld metal E309L. Despite the high average value of hardness (220HV) obtained in the FZ of the weld with the weld metal E316L, this did not reach maximum hardness required for austenitic steels for use in oil industry, which according to the standard NACE MR0175[13] requires a hardness of up to 250 HV.

4 CONCLUSION

From our analysis and observations, one can conclude that:

1. For two types of filler metals was a large grain growth in ZTA, which weakens the material in this region;
2. The hardness profile in the HAZ of AISI 444 showed significant similarity to the two electrodes (E309L and E316L);
3. The weldments with the filler metal E316L proved considerably more hardness in FZ in relation to the weldments with the filler metal E309L;
4. In tensile tests, the welded joints with filler metal E309L presented mechanical properties considerably higher than the welded joints with filler metal E316L;
5. The electrode E309L presents as the filler metal more suitable for use in welding repair to be carried out in equipment consisting of ferritic stainless steel AISI 444. The microstructure formed by a network of delta ferrite discontinuous difficult to crack propagation of FZ to the HAZ steel AISI 444.

Acknowledgments

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