Comparison of resistance to corrosion on haz of a ferritic stainless steel by different surface finishings

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ABSTRACT. Certain techniques, comprising machining and GTAW dressing, have been used in the weld bead edge (region of the welded joint between the weld metal and the base metal) to increase the fillet radius of the region by reducing the stress concentrator factor, decreasing roughness, and increasing the life of weldings. Moreover, TIG Dressing may also provide a smooth change in the radius of the curvature and change the average grain size and promote a microstructural variation through the reflow of this region. Current study analyzes the effect of surface finish of the Heat Affected Zone (HAZ) on resistance to corrosion of welded joints of simple deposition under plate by using machining techniques with sandpaper of different particle sizes and GTAW Dressing, comparing the effect of the two techniques in the resistance to corrosion in environments with chloride ions. ACE P410D ferritic stainless steel was employed as base metal and austenitic wire 308L for welding. Results showed that the condition sweetened with GTAW Dressing with pure argon at current 100A generated the lowest mass loss among the conditions under analysis.

Keywords: ferritic stainless steel P410D, surface finish by machining, surface finish by TIG Dressing, corrosion.

Comparar a resistência à corrosão sobre a zac de um aço inoxidável ferrítico por diferentes técnicas de acabamento superficial

RESUMO. Algumas técnicas, dentre elas, a usinagem e o TIG Dressing têm sido utilizadas na borda do cordão de solda (região da junta soldada entre o metal de solda e o metal de base) para aumentar o raio de concordância dessa região, diminuindo o fator concentrador de tensão, além de diminuir a rugosidade, aumentando a resistência à fadiga dos conjuntos soldados. Além dessas mudanças, o TIG Dressing também pode proporcionar uma mudança suave no raio de curvatura, além de alterar o tamanho médio dos grãos e promover uma variação microestrutural através da refusão dessa região. Baseado neste contexto, a proposta deste trabalho foi analisar o efeito do acabamento superficial da ZAC na resistência à corrosão de juntas soldadas de simples deposição sob chapa, usando técnicas de usinagem com o auxílio de lixas de granulometrias distintas e TIG Dressing, comparando o efeito das duas técnicas na resistência à corrosão em meios contendo íons cloretos. Para tanto, foi utilizado o aço inoxidável ferrítico ACEP410D com o metal de base e um arame austenítico 308 L para efetuar as soldas. Os resultados mostraram que a condição adoçada com TIG Dressing usando argônio puro na corrente de 100A foi a que gerou menor perda de massa dentre as condições estudadas.

Palavras-chave: aço inoxidável ferrítico P410D, acabamento superficial por usinagem, acabamento superficial por TIG Dressing, corrosão.

Introduction

Stainless steels of different chemical compositions are commonly used in many industries. According to Gentil (2003) and Padilla and Guedes (1995), these steels have a different behavior from carbon steels due to the presence of the passive layer which causes the steel´s resistance to corrosion. However, the layer of hydrated oxides of Cr and Fe undergoes changes during the welding process and thereby the life span of the welding is reduced. Among the steels, ferritic stainless steel includes 15-20% chromium, low carbon content and a very low percentage of nickel. According to Kin et al. (2012), ferritic stainless steels (FSs) replace aluminized steel due to their excellent resistance to corrosion. In spite of these relevant properties, these steels undergo great loss of toughness with increase of grains in the welded areas and due to their CCC structure.

The ferritic stainless steel P410D Ace, manufactured by Aperam with 11% chromium, has a corrosion resistant below alloy steel and above that in construction material. According to Aperam (2012), steels in the annealed state has a resistance to corrosion in wet environments free from chloride ions and good characteristics for welded construction in which HAZ, essentially made of martensite, with low carbon contents and fine grain size, has high resilience rates at low temperatures. They are greatly efficient in sugar cane processing plants, filling in distillation columns in the oil industry, and in others. One of the major problems of these steels is the loss of ductility on the welded areas, which usually become brittle and less resistant to corrosion. Grain increase, the partial formation of martensite and chromium carbonitride precipitation are generally the main causes of this problem, albeit one of the attractions for the use of this material in current research (BRANCO et al., 1999).

According to the IIW document prepared by Haagensen and Maddox (2013), GTAW Dressing is a technique to increase the correlation of welded joints, with minimum tensions and imperfections in the region, and to enhance a microstructural change, with a resistance increase to fatigue in foot bead. On the other hand, Baptista et al. (2008) found that the concentrator voltage factor in welding decreased with an increase in fillet radius, generated by techniques of surface modification. Based on this study, Pedersen et al. (2010) observed that GTAW Dressing produced a smoother transition between the welding metal and the basal metal, although one of the limitations of this technique has been observed as a slight change in torch angle and welding speed. The latter are important variables to recast a welding that modifies the geometry throughout the cord. Studies by Haagensen and Maddox (2013) showed that this technique provides a 3.0 mm smooth radius in the welded joint which may be extended further. However, the technique has been little used to implement weldings to reduce corrosion when compared to conventional machining techniques for this purpose. Studies by Guozhi et al. (2007) showed that GTAW Dressing also minimized corrosion effects on HAZ. It is actually associated with the formation of a smooth curvature radius between the welding metal and the base metal, thereby minimizing stresses generated in the region.

According to the same author, sweetening machining technique with rotating tip had a significant influence on wear by corrosion in the region under analysis. It is associated to the final sweetened edge geometry by increasing the stress concentrator factor in the region. However, the technique did not prove to be more efficient than GTAW Dressing with changes in the roughness of the area under analysis.

Current assay examined the effect of different roughness in HAZ produced by the conventional technique of finish machining by a rotating nozzle, followed by coating with sandpaper grit sizes, ranging between 100 and 1200 mesh, and then compared with the GTAW Dressing effect in the resistance to corrosion of the studied area. Ferritic stainless steel ACE P410D was employed as base metal, coupled to an austenitic stainless steel wire ER 308L to achieve weldings by GMAW process with spray transfer and GTAW Dressing without filler wire. Results showed that the condition sweetened with GTAW Dressing using pure argon at 100 A current generated the lowest mass loss within the conditions under analysis.

Material and methods

The methodology comprised four stages: Part (I) - Welding of plates by GMAW, followed by stripping and repassivation; Part (II) - weld bead edge sugaring GMAW, GTAW Dressing and machining; Part (III) - Preparation of samples for immersion corrosion test; Part (IV) - Corrosion Assessment of HAZ by mass loss.

Part (I): Welding followed by etching and repassivation of test plates

Non-stabilized ferritic Ace P410D with low chromium and Ni contents (for low costs) was chosen, coupled to a nobler welding metal (an austenitic stainless steel, ER 308L), indicating superior corrosion to the metal base. The latter had to be cathodic when compared to the base metal, with HAZ more susceptible to corrosion. Table 1 shows the chemical composition of the base metal and wire provided by the manufacturer used in GMAW welding process. The base metal consisted of a 200 x 75 x 6.35 mm metal sheet and the wire had a 1.2 mm diameter.

Table 1. Chemical composition (%) supplied by the manufacturer of basal metal Ace P410D and ER308L wire.

Type	Elements										
	C	Mn	Si	Cr	Ni	Mo	Cu	Co	P	S	Nb
Ace P410D	0.01	0.61	0.49	11.22	0.30	0.02	0.02	0.01	-	0.01	-
Wire ER308L	0.02	1.76	0.42	19.83	9.96	0.07	0.05	0.0	0.01	0.01	0.01

GTAW welding employed multiprocess source electronic devices and automated system to position and move the welding torch locked to a table of coordinates controlled by a mechanical system with an electronic control to control the torch´s speed. GTAW welding were made at constant current

(to facilitate repeatability), in a spray transfer mode (with more stable arc, free from spills that may be sites for early corrosion), in a pulling welding condition (more convex) by a 10° attack angle. Table 2 shows the parameters to weld the ferritic stainless steel plates Ace P410D in the pulling direction.

Table 2. Welding parameters MIG / MAG welding with spray transfer in pulling welding condition.

Wire	Base metal	WS (mm min.$^{-1}$)	Operating parameters Gas (98%Ar + 2%O$_2$)				
			Pulling condition				
			Fs (mm min.$^{-1}$)	Ac (A)	Av (A)	Flow (L min.$^{-1}$)	BCDP (mm)
308 L	410 D	300	8000	241	29.0	15.0	21.0

Note: WS: welding speed; Fs: Feeding Speed; Ac: Average current; Av: average voltage; BCDP: Beak contact distance piece.

After defining the welding parameters, a system was designed to weld beneath the ferritic stainless steel plates Ace P410D to measure susceptibility to corrosion on HAZ. Two strands were welded in parallel beneath the plate to increase HAZ restriction by a 12 mm-distance between them. Etching followed by repassivation was performed with a solution prepared with 20% nitric acid (HNO$_3$) and 2% weight of sodium dichromate (Na$_2$Cr$_2$O$_7$. 2H$_2$O) according to ASTM A 380-06 (2006) ASTM A 967-05 (2005), respectively. Figure 1 shows the layout of the cords under the sheet after etching and repassivation. The edges of the weld beads were sweetened with GTAW Dressing techniques and machined.
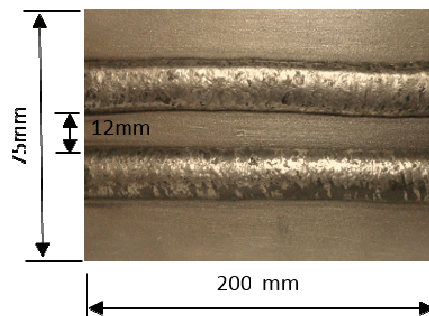

Figure 1. Welded test plate with MIG / MAG in the pulling direction.

Part (II): Sweetening of edges of weld beads MIG / MAG by TIG Dressing and machining

GTAW Dressing technique was employed on the edge of the GMAW welding seams by varying current and welding speed. Weaving was performed with a pendulum-type oscillator with adjustable parameters to insert oscillation frequency (f), swing angle (θ), side stop time (sst) and central downtime (CDt). Table 3 shows the parameters for weaving TIG Dressing.

Table 3. Parameters of TIG Dressing with weaving and current change.

Sweetening Parameters: gas mixture: 12l min.$^{-1}$; Θ$_{attack}$ = 10°; Θ$_{work}$ = 78,2°; n. nozzle = 8						
Parameters of weaving: A: 1.2°; Frequency: 1 Hz; TPL: 0.35 s						
	Gas mixture	I (A)	Vs (mm s^{-1})	DWP (mm)	DEB (mm)	R (mm)
Ø$_{wire}$ 1.6mm	100% Ar	100	0.8	3.0	0.0	24.3
		150				-
	96.2% Ar +3.8% N$_2$	100	0.8	3.0	0.0	-
		150				-
	99.0% Ar +1.0% N$_2$	100	0.8	3.0	0.0	19.3
		150				-

Figure 2 shows devices used in sweetening Dressing and GTAW torch. A schematic representation for implementing the position GTAW Dressing weld bead on the edge of GTAW welding.
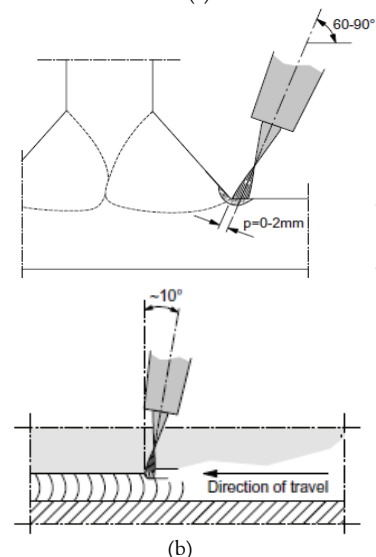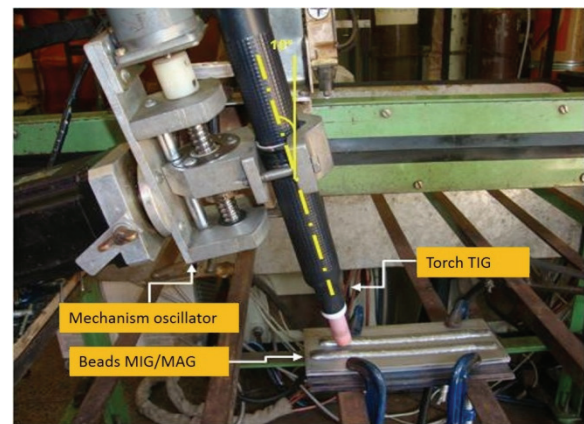

Figure 2. Sweetening by TIG Dressing. (a) Set of devices in sweetening with TIG Dressing of the edge of the weld MIG / MAG; (b) Schematic representation of the torch position. (Kado et al. 1975)

After setting the parameters, sweetness was performed by weaving on the welding beads of edges, obtaining microstructure, as shown in Figure 3.
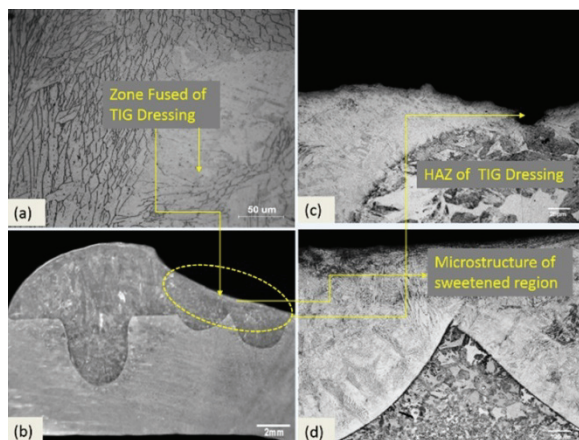
Figure 3. Sweetened region with TIG Dressing: (a) Microstructure of ZF; (b) Micrograph of sweetened region; (c) Heat Affected Zone (HAZ) of TIG Dressing; (d) Microstructure of ZF (attack with Marble's).

So that the edge of the welding beads GTAW by machining could be sweetened, the plates were cut into samples measuring 75 x 25.4 x 6.35 mm, and then sweetened with an abrasive aluminum rotating conical nozzle (Al$_2$O$_3$) B-41, particle size 60 mesh, coupled to a drill and portable grinding. For the repeatability of the machined fillet radius, a rigid polymer mask was manufactured for overlapping on all samples after machining, and thus ensuring that the sweetness section had the same fillet radius. Figure 4 shows procedure for sweetening the welding bead edge. After sweetening, the samples were abraded with 100 -1200 mesh sandpaper grain.
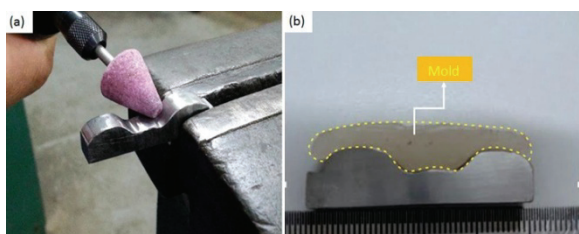

Figure 4. (a) Sweetening on welding bead edge MIG / MAG for machining; (b) manufacture of mask.

Part (III) – Preparation of samples for immersion corrosion test

Samples sized 75 x 25.4 x 6.35 mm were cut from the cross section of the test plates and underwent immersion corrosion test by using a sodium chloride solution at a 3.5% concentration, following ASTM G61-86 (1986). The solution was heated at 50±2°C and samples were exposed for 5, 10 and 20 hours for proper identification of pits in the HAZ region. The 20-hour condition was chosen since it presented a good identification of pits and reasonable mass loss. Therefore, the HAZ region was exposed to aggressive media and the remaining

section was isolated with synthetic enamel. Further, a sample sanded and attacked with Marble's was analyzed by light microscopy to measure the extent of the study area by an image analyzer. Figure 5 shows the extent of this region and the samples treated with sodium chloride solution.
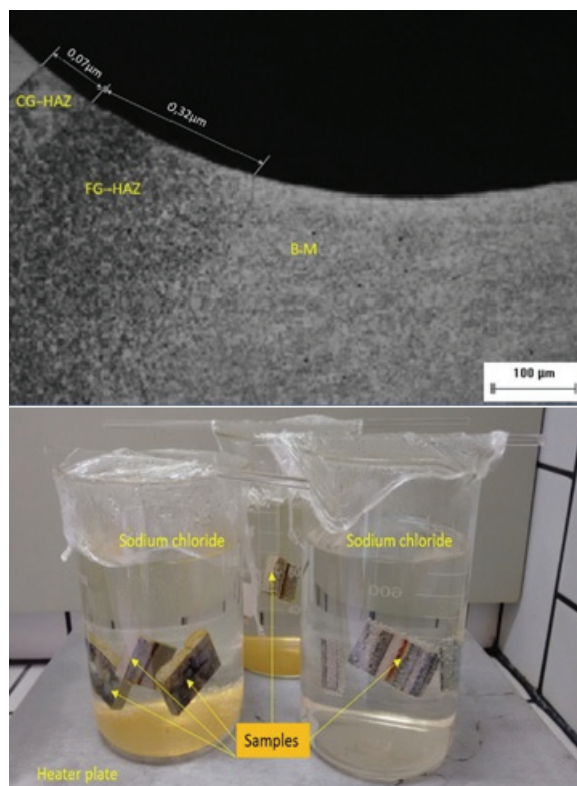

Figure 5. Extension of HAZ. CG-HAZ (coarse particles in the Heat Affected Zone); FG-HAZ (Fine Granulometry in the Heat Affected Zone); BM (base metal).

The samples were washed, dried and weighed before and after the immersion test; HAZ mass loss was calculated, following ASTM G 31-72 (1972). After the corrosion test, the samples were evaluated microscopically, as shown in Figure 6, for assessing the extent of corrosion by linear extension defined in Figure 5.

Results and discussion

Part (IV) – Corrosion evaluation on HAZ by mass loss, employing TIG Dressing technique on the edge of the strands MIG / MAG

Pedersen at al. (2010) showed that in addition to stresses generated by the agreement between the welding metal and the base metal, the microstructural heterogeneities and non-uniform distribution of residual stresses increased susceptibility to corrosion in HAZ under the studied conditions. According to Fedele (2010),

microstructure diversity increases the probability of active sites for corrosion. Therefore, HAZ of GTAW Dressing under discussion presents martensite within a ferrite matrix that stands out as the most reactive, with anodic behavior when compared to ferrite in media with chloride ions, as shown in Figure 7.
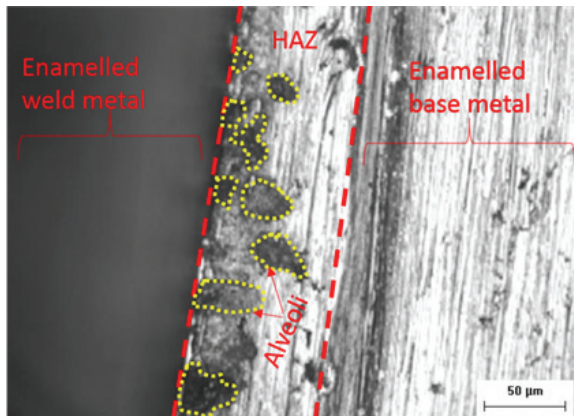

Figure 6. Optical microscopy of the sample ACE P410D stainless steel welded with wire ER 308L after immersed in sodium chloride solution ($NaCl_3$).
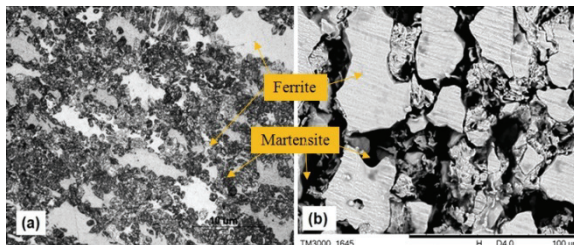

Figure 7. Microconstituents of martensite and ferrite formed in the heat-affected zone (HAZ) of ferritic stainless steel Ace P410D: (a) before attack by $NaCl_3$; (b) after attack by $NaCl_3$.

Besides research by the above-mentioned author, other studies by Beom et al. (2010) showed that HAZ in the welded part of these steels became more susceptible to corrosion of the weld due to martensite, considered a high energy microconstituent when compared to ferrite. Further, Alvarez et al. (2013) reported that percentage and distribution of martensite, generated by deformation of different austenitic stainless steels, caused the anodic dissolution of the steels. Thus, GTAW Dressing technique used at the edge of the weld GMAW reduced wear due to corrosion in the HAZ of GTAW of samples submitted during twenty hours to sodium chloride ($NaCl_3$) heated at 50±2°C. However, argon shielding gas was more resistant to attack by chloride ions, as Figure 8 demonstrates, perhaps due to the influence of the protective gas in the solidification mode of HAZ

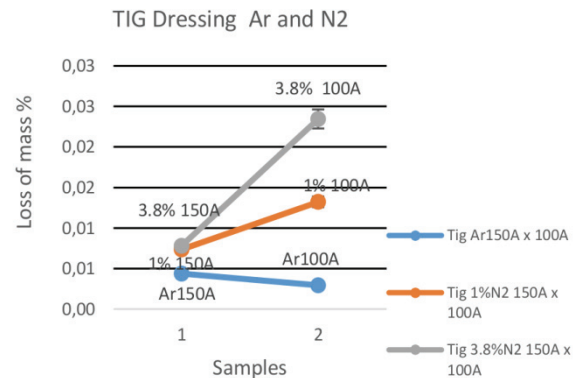which influenced average size and / or amount of microconstituents for corrosion.

Figure 8. Mass loss of the samples sweetened with TIG Dressing with gases (100% Ar, 1% N_2+Ar, 3.8% N_2+Ar).

Employing machining technique on the edge of the strands MIG / MAG

Diniz et al. (2003) showed that the smoother surface finish of cord edge GMAW favored less wear on HAZ but failed to demonstrate this effect between the different types of roughness. A study was thus conducted by comparing samples with three types of surface finish, in which three samples were sweetened at the edge of the cord by a 60-mesh aluminum tip and three were finished with 220, 600 and 1200 mesh grained sandpaper. They were compared to the effect of surface finish on HAZ wear. Table 4 shows that roughness diminished with decrease in abrasives diameter, enhancing a smoother finish.

Table 4. Roughness according to sandpaper grain size.

Granulometry of sandpaper (Mesh)	Roughness (μm)
280	0.093
600	0.052
1200	0.023

When weight loss results (in Figure 9) of the three types of sandpaper used on the edge weld bead GMAW were compared, the mass loss was lower for samples sanded with 1200-mesh sandpaper, due to lower roughness rate. Diniz et al. (2003) reported that the corrosion resistance depended on the surface morphology, or rather, the smoother the surface, the greater is the resistance to corrosion. Kato and Otoguro (1978) also showed that in welded areas, among other factors, roughness patterns determine the surface finish. A rougher surface may cause the breakdown of the passive film of stainless steel, transforming it into active and thus subjected to corrosion.
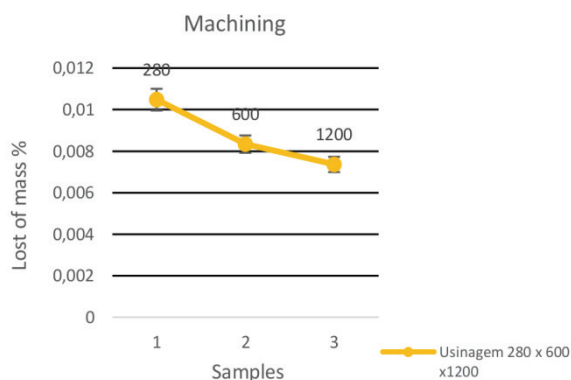
Figure 9. Mass loss of the samples sweetened by machining.

Comparison of mass loss on HAZ by sweetening techniques for machining and TIG Dressing

In order to compare the effect of sweetening forms by machining and GTAW Dressing on HAZ, Figure 10 shows the overall evaluation of mass loss on HAZ of GMAW welding. Within the conditions studied, GTAW Dressing 100% Ar, with current 100 A, had the lowest wear. The above demonstrates that this technique is more wear resistant than the sandpaper machining technique. Haagensen and Maddox (2013) showed a similar effect attributing result to a smoother agreement promoted by GTAW Dressing technique by reducing the stress concentrator factor on ZAC of GMAW that directly affected this characteristic. Moreover, a more uniform distribution and / or average size of the region´s microconstituents, enhanced by GTAW Dressing technique, may have influenced this outcome too.
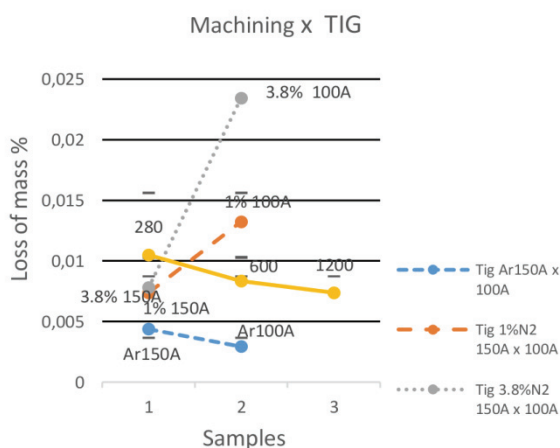

Figure 10. Comparison between sweetening machining techniques and TIG Dressing.

Studies by Branco et al. (1999) and Nussbaumer (2008) demonstrated that machining operations for smoother surfaces may bring out inner surface defects, such as porosity, lack of fusion and cracks possibly caused by high stress. For these reasons, it is preferable to use the reflow pass technique for welding with a smoother profile than run the risk of obtaining welding with bites or surface cavities or more serious defects by machining.

Conclusion

Two techniques were evaluated during the development of current assay. They identified the wear corrosion in the welding bead edge of the area in which HAZ was the region used for this analysis. Results provided the following conclusions:

- Samples sweetened at the edge of the weld bead increased wear when compared with results from GTAW Dressing technique. However, the technique enhanced a smoother finish and contributed towards a smaller mass loss when finer particle size abrasives were employed;
- Among the analyzed conditions, GTAW Dressing with argon gas stream at 100A produced the lowest mass loss. However, 3.8% N_2 stream at 100A had the highest wear rate;
- The technique analysis to verify the mass loss on HAZ was effective to compare the conditions under analysis.

References

ALVAREZ, S. M.; BAUTISTA, A.; VELASCO, F. Influence of strain-induced martensite in the anodic dissolution of austenitic stainless steels in acid medium. **Corrosion Science**, v. 69, p. 130-138, 2013.

APERAM. **Aço inoxidável Ferrítico Ace P410D**. Available from: <http://www.arcelormittalinoxbrasil.com.br/port/arquivos/AcoInoxPortuguesP410D.pdf>. Access on: 25 fev. 2012.

ASTM A 380-06. **Standard practice for cleaning, descaling, and passivation of stainless steel parts, equipment and systems**. West Conshohocken: ASTM, 2006.

ASTM A 967-05. **Standard specification for chemical passivation treatments for stainless steel parts**. West Conshohocken: ASTM, 2005.

ASTM G31-72. **Standard Practice for Laboratory Immersion Corrosion Testing of Metals**. West Conshohocken: ASTM, 1972.

ASTM G61-86. **Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of iron-, Nickel-, or Cobalt-Based Alloys**. West Conshohocken: ASTM, 1986.

BAPTISTA, R.; INFANTE, V.; BRANCO, C. M. Study of the fatigue behavior in welded joints of stainless steels treated by weld toe grinding and subjected to salt water corrosion. **International Journal of Fatigue**, v. 30, n. 3, p. 453-462, 2008.

BEOM, W. J.; YUN, K. S.; PARK, C. J.; RYU, T. J.; KIM, Y. H. Comparison of influences of NaCl and $CaCl_2$

on the corrosion of 11 and 17% Cr ferritic stainless steels during cyclic corrosion test. **Corrosion Science**, v. 52, n. 3, p. 734-739, 2010.

BRANCO, C. M.; FERNANDES, A. A.; CASTRO, P. M. S. T. **Fadiga de estruturas soldadas**. 2. ed. Lisboa: Fundação Calouste Gulbenkian, 1999.

DINIZ, A. E.; MARCONDES, F. C.; COPPINI, N. L. **Tecnologia da usinagem dos metais**. 4. ed. São Paulo: Artliber, 2003.

FEDELE, R. A. Corrosão intergranular em juntas soldadas - Parte I. **Soldagem e Inspeção**, Ano 6, n. 3, p. 1-6, 2010.

GENTIL, V. **Corrosão**. 4. ed. Rio de Janeiro: LTC, 2003.

GUOZHI, X.; XIAOYAN, L.; KEYU, W.; XIANGYUN, M.; DONGJIE, Z.; PINGHUA, L. Corrosion Characteristics of Plasma-Sprayed Ni-Coated WC Coatings Comparison with different Pos-Treatment. **Corrosion Science**. V. 49, p. 662-671, 2007.

HAAGENSEN, P. J.; MADDOX, S. J. **IIW on methods for improving the fatigue strength of welded joints**. IIW-2142-110, 2013.

KADO, S. **The Method of TIG dressing**. International Institute of Welding, 1975. (Document XIII-773-75)

KATO, C.; OTOGURO, Y. Grooving corrosion in electric resistance welded steel pipe in sea water. **Corrosion Science**, v. 18, n. 1, p. 61-74, 1978.

KIN, K. J.; LEE, S. J.; KIM, Y. K. Intergranular precipitation and corrosion in weld of low cr ferritic stainless steel. **Metals and Materials International**, v. 18, n. 4, p. 619-624, 2012.

NUSSBAUMER, A. C. **Influence of residual stresses and pos-welding improvement methods: course on fadigue and fracture mechanics**. Course on LEFM, 2008. Available from: <https://estudogeral.sib.uc.pt/bitstream/10316/10738/1/cours%20fatigue-LEFM.pdf>. Access on: July, 2015.

PADILHA, A. F.; GUEDES, L. C. **Aços inoxidáveis austeníticos**. São Paulo: ABM, 1995.

PEDERSEN, M. M.; MOURITSEN, O.; HANSEN, M. R.; ANDERSEN, J. G.; WENDERBY, J. Comparison of post weld treatment of high strength steel welded joints in medium cycle fatigue. **Welding in the World**, v. 54, n. 7/8, 2010.