Comparative study between butt and overlap welded of dissimilar steels (Structural - Stainless) under monotonic and cycled load

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ABSTRACT. *This study describes the comparative evaluation under monotonic and cycled load (butt and overlap welded) of dissimilar steels; structural ASTM A537 (I) and stainless ASTM A240 (304L) through GMAW, Argon as protecting gas and ASTM A240 (308L) as a supplier material. Microstructures were contrasted in different zones of each joint, focus on the Heat Affected Zone (HAZ) and fusion lines. The following mechanical tests were compared between both welding joint (WJ): Vickers hardness profile, tension, bending, and axial fatigue. A statistically based model was determined for each configuration that allows predicting the fatigue life of Wöhler field and also the fatigue factor. Vickers profile show high values of microhardness in the HAZ, near the fusion line between weld and stainless. Tension and axial fatigue tests indicated similar behavior between WJ and structural steel (butt joint); and similar behavior between WJ and stainless (overlap joint). Dissimilar unions (butt and overlap) have mechanical and microstructure properties under monotonic and cyclic loading, which can be considered adequate to withstand the mechanical requirements in service conditions, despite relatively high values of hardness in the HAZ.*

INTRODUCTION

Dissimilar welds have been developed in recent years in applications of pressure vessels and pipes, heat exchangers, boilers, and other components designed for transport and storage of fluids due to the increasingly growing deployment of joints between different Base Metals (BM), mainly for cost reasons. Antecedent is presented as the evaluation of mechanical behavior of the dissimilar butt and overlap welding between stainless and structural steel using GMAW process, under monotonic and cyclic loads [1, 2]. On this occasion, the overall aim is to compare between butt and overlap study the mechanical behavior of ASTM A240 stainless steel (304L), BM1 [3], overlap welded with structural steel A537 (class I), BM2 [4], using ASTM A240 steel (ER-308L) as a filler metal (ANSI/AWS A5.9/A5.9M: 2006) [5] also under monotonic load, without subjecting the joint to TT before and after welding. The research focused on characterizing the mechanical properties of the weld; examine the influence of the factors that affect the quality of welding on the mechanical behavior of the joint and to evaluate the influence of the type of load applied the mechanical behavior of the union. To achieve these aims, the work focused on the factors that affect the quality of welding, such as, welding defects (surface and internal cracks, slag deposits and undermining), microstructure, extent of the HAZ and mechanical properties (profile of hardness, tension, bending and axial fatigue).

EXPERIMENTAL PROCEDURE

The materials used were a 304L and an A537 plates, both (1.200x2.400x 4.76) mm. The butt weld was made at top, in pieces of 280 mm in length, with bevels of 60 degrees, flat according to ASME Section IX QW-463.1 [6], using GMAW with argon and a FM consumption of SS ASTM A240 (308L) of 1.6 mm, on a single pass, following the scheme illustrated in Fig. 1 [1]. The overlap welding was done in double cord, pieces of SS 200 mm wide and 400 mm in length, flat position also according to the ASME Code Section IX QW-463.1 [6], using the GMAW, argon and filler metal of 1.6 mm in diameter applying one pass, and following the scheme illustrated in Fig. 2 [2].

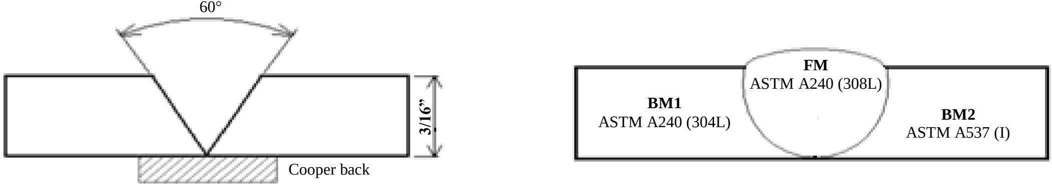


Fig. 1. Setting the weld, bevel and location of the materials involved.

Fig. 2. Welded Joint and materials involved

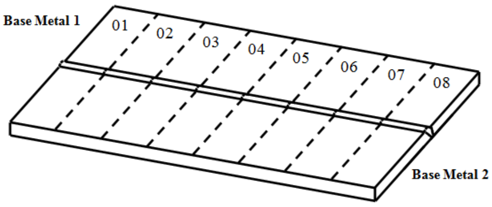


Fig. 3. Distribution of the specimens

Welding parameters were: current, I = 250 A; voltage, E = 27 V; energy, Q_0 = E.I = 6.75 kW; Heat Input, HI = 0.80 KJ/mm; wire speed = 4 m/min; and arc speed = 0.508 m/min; AWS specifications [7]. After welding, each sample was subjected to Not Destructive Test (NDT) [6], by penetrating liquids and ultrasound techniques, to rule out the presence of cracks or other defects and inner surface which could alter the results of mechanical tests. The chemical composition of BM was checked, using Atomic Absorption Spectrophotometry method (AAS) and Energy Dispersive X-ray Analysis (EDX) [6]. From each sample welded, cut WM representative samples containing the BM1, BM2 and the HAZ. Samples were metallographically prepared using conventional mechanical polishing method, according to ASTM standard E3 [8].

Final polishing was done with diamond paste of 1 μm. Samples were attacked with Vilella reagent (45 ml glycerol, 15 ml nitric acid, hydrochloric acid 30 ml) for BM1 and Nital 3% (100 ml Ethyl Alcohol 96% nitric acid +10 ml) for BM2, while the weld was attacked with 3% Nital to reveal the interface between the SS and ASS, and then with Vilella to form the profile of the weld microstructure. All samples were analyzed by using a Scanning Electron Microscopy (SEM) PHILIPS, model XL 30 with EDX. Microhardness tests, tensile, and face guided bending, were performed. Profiles Vickers hardness (HV) was measured, covering BM1 & BM2, HAZ and WM. A MITUTOYO microhardness was used, MVK-H1 model, calibrated applying a load of 100 g for 15 s correspondence to ASTM E-92 [9]. Samples were selected for tensile [10], bending and axial fatigue as shown and detailed in Fig. 3. The ends of the welded plate were discarded (01 & 08); two specimens were tested for each BM and two more of WM, accordance to ASME Section IX [6]. Specimens were machined in a conventional manner with a universal milling machine, using coolant to prevent the heat generated during machining operations affect samples microstructure. Tensile and axial fatigue tests (Fig. 4) were performed on a Universal Tensile Machine; PBI-20 Model, 20 ton. For guided bend tests (Fig. 5), two face and two root specimens were prepared on top and four face specimens were prepared for each section of overlop welded. To observe ductile material behavior without actually generate in the area of greatest distortion of the specimen failure greater than 3.2 mm (1/8"), the specimens were bent up to 180º until U form, placing welding in the area under greater strain. To do this, a 40 Ton hydraulic press was used, dimensions accordance to AWS [7] in terms of yield strength of the WM so previously the tensile tests at the joints were performed. Referencing the yield strength of the WM and ASME code [6] a base type A (up to 360 MPa) was used.

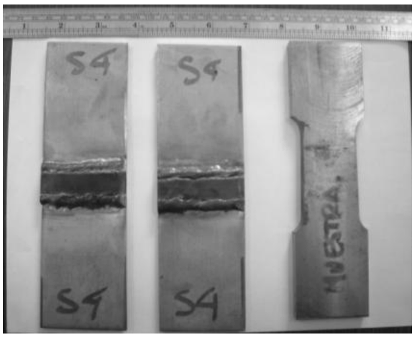


Fig. 4. Samples for tensile test [1]

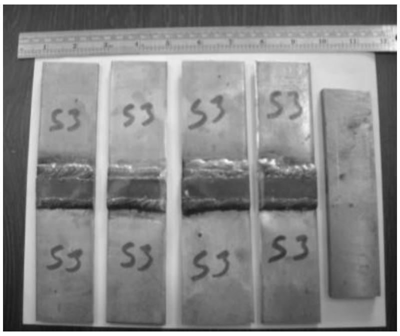


Fig. 5. Samples for bending test [2]

RESULTS AND DISCUSSION

The welding join (WJ) was evaluated in two stages: first the BM1-MA (304L-308L), and then the BM2-MA (308L-A537), the results of EDX analysis are shown in Table 1 and illustrated in Fig. 6. It were calculated the Cr and Ni equivalent according to Schaeffler, DeLong, WRC and Creq/Nieq [11], to characterize the weld with the composition obtained in the laboratory (EDX). Table 2.

Table 1. BM & WJ COMPOSITION (% MASS) [12].

Element	**A537 (I)**	**BM1:304L**	**WJ (EDX)**	**304L-308L**	**308L-A537(I)**	**Average**
C	0,230	0,028	0,040	0,033	0,154	0,093
Cr	0,000	17,74	15,84	18,304	7,836	13,070
Ni	0,000	9,465	9,180	9,673	4,018	6,846
Mo	0,000	0,000	0,000	0,000	0,000	0,000
Mn	1,145	1,735	1,730	2,033	1,537	1,785
Si	0,435	0,425	0,560	0,610	0,529	0,570
N	0,000	0,000	0,000	0,055	0,056	0,055
P	0,000	0,000	0,000	0,016	0,016	0,016
S	0,000	0,000	0,000	0,012	0,012	0,012
Cu	0,000	0,000	0,000	0,000	0,000	0,000

Table 2. SCHAEFFLER, DELONG, WRC & CR_{EQ}/NI_{EQ} [12].

<table>
<tr><th colspan="4">SCHAEFFLER [1, 2]</th></tr>
<tr><th>Joint</th><th>304L-308L</th><th>308L-A537(I)</th><th>Average</th></tr>
<tr><td>Cr eq</td><td>19,219</td><td>8,629</td><td>13,924</td></tr>
<tr><td>Ni eq</td><td>11,670</td><td>9,396</td><td>10,533</td></tr>
<tr><th colspan="4">DELONG [1, 2]</th></tr>
<tr><td>Cr eq</td><td>19,219</td><td>8,629</td><td>13,924</td></tr>
<tr><td>Ni eq</td><td>13,306</td><td>11,084</td><td>12,195</td></tr>
<tr><th colspan="4">WRC [1, 2]</th></tr>
<tr><td>Cr eq</td><td>18,304</td><td>7,836</td><td>13,070</td></tr>
<tr><td>Ni eq</td><td>11,908</td><td>10,521</td><td>11,215</td></tr>
<tr><th colspan="4">Cr_{eq}/Ni_{eq} [1, 2]</th></tr>
<tr><td>Creq/Nieq</td><td>1,647</td><td>0,918</td><td>1,322</td></tr>
<tr><td>%P+%S</td><td>0,027</td><td>0,028</td><td>0,028</td></tr>
</table>

Fig. 6 shows the sweep of microhardness and microhardness profile of on top welded sample, measured in the middle, upper third and lower third of the weld, similar trend was observed in all three measurements. Fig. 7 shows the sweep of hardness and orientation used in the measurements (the middle, upper third and lower third of the weld), showing a similar trend in the three measurements. It can see that the weld presents a progressive increase in hardness values between the structural steel and stainless steel, standing in a range between 96 and 310 HV. The same way, could appreciate at near the fusion line between weld and 304L stainless steel shows the maximum hardness of 310 HV which is attributed to the existence of a dendritic structure at the interface to the weld due to melting of filler, while, near the fusion line between weld and structural steel, shows a slight increase from 96 HV to 110 HV product of the decomposition of austenite as it temperature decreases (Fig. 8).

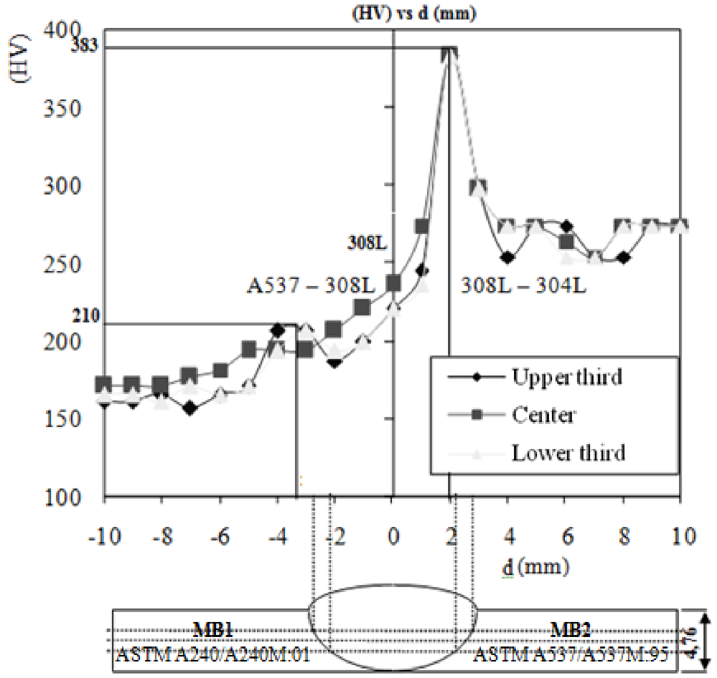
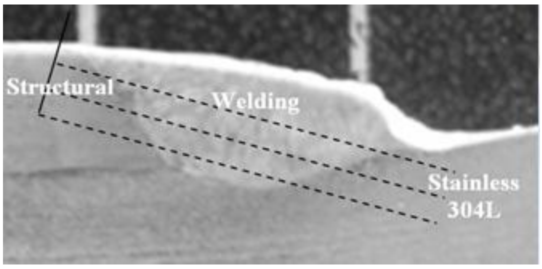


Fig. 6. Vickers hardness profile (butt joint)



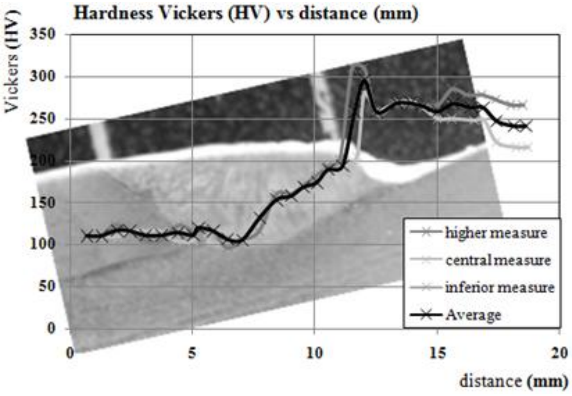


Fig. 7. Microstructure (overlap)

Fig. 8. Vickers hardness profile (overlap)

The properties of BM1, BM2, FM and WJ, butt and overlapping, are reported in Table 3. Fig. 9 shows the engineering stress-strain curve, higher strength and ductility observed in the overlapping followed by the stainless steel, similar resistance between the structural and butt-welded, and lower ductility in the overlap-welded. The tensile strength (Su) and the yield stress (Sy) of the bases materials specimens tested are higher than those required by ASTM [3, 4]. It may notice that the results of butt weld specimen are similar to BM2 values and the overlap to BM1.

Table 3.Tensile mechanical properties of the samples (obtained in the laboratory) [1, 2].

Properties	**Sy**	**Su**	**Elong.**
Material	**(MPa)**	**(MPa)**	**(%)**
BM1 A240 (304L)	388±3	648±2	48±1
BM2 A537 (I)	265±6	458±2	34±1
FM A240 (ER-308L)	481±3	585±2	40±2
Butt-welded (BW)	283±3	456±2	25±2
Overlap-welded(OW)	390±2	652±2	47±2

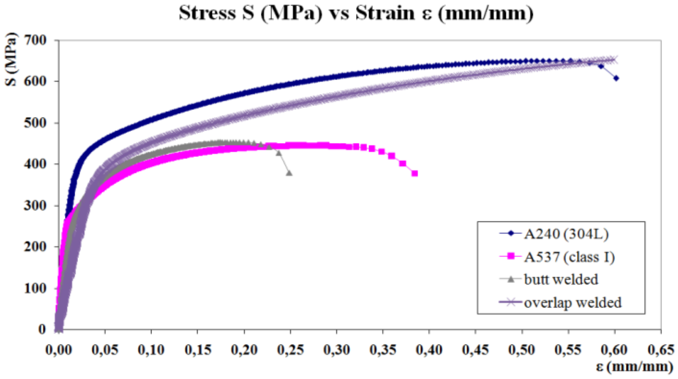


Fig. 9. Engineering stress-strain curve [1, 2].

Is important to mention that the butt-welded specimens, tensile test, failed outside of the HAZ and the weld, specifically in the MB2 A537 (I) on top and MB1 A240 overlap (Fig. 10). The specimens welded as overlap, suffering deformation around the ductile fracture in, away from the HAZ without affecting the weld, as evidenced in Fig. 10 b. The results are consistent with the microstructure presented. The regions hardest phases that modify the ferrite response of the material when it is under load. These structures make the material more resistant to being deformed, leading to an increased effort to produce plastic deformation. At the same time tends to accept a lower degree of elongation.

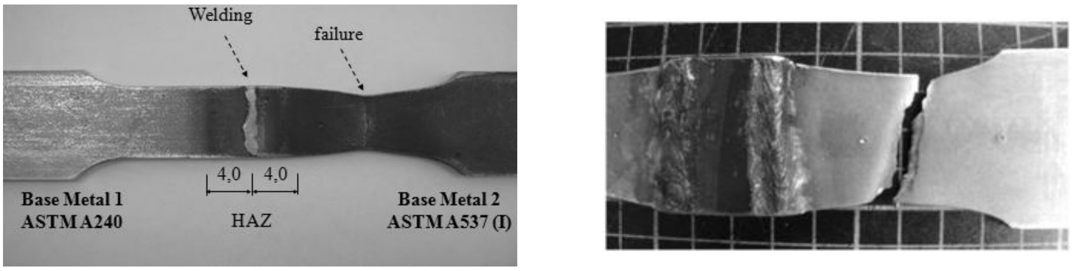


Fig. 10. Specimen butt and overlap welded, tested in tension, measures in mm [1, 2].

To determine the fatigue life for BM, & WM, was taken as reference the relationship of fatigue (0.4) with respect to maximum stress (σ_{UTS}) previously determined by tensile test [1, 2]. Diagram was constructed for each BM & WM, resulting in the curve for welded joint next above that of BM2. The values determined are reported in Table 4.

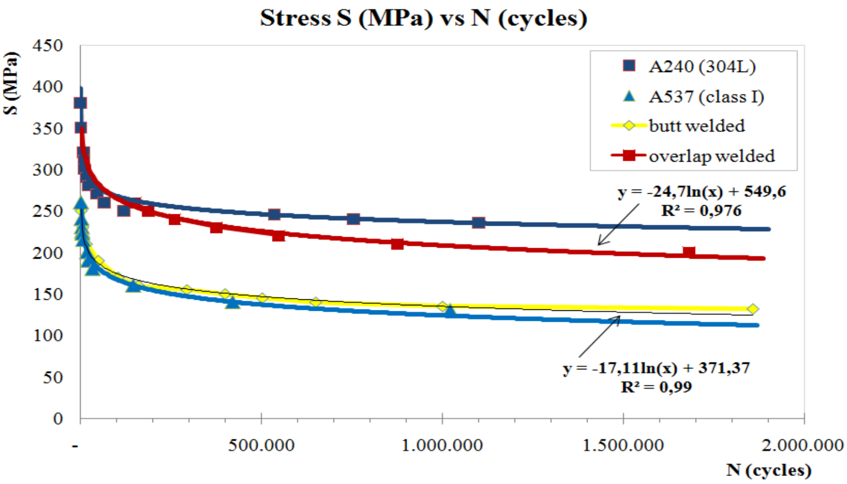


Fig. 11. Whöler Diagram. BM1 A240, BM2 A537 & WM.

It can be seen from the diagram that fatigue strength of WM is 8% higher than that determined for BM2, which reinforces the non-existence of internal cracking a decisive influence on the opening of crack and consequently in the resistance to fatigue of the welded joint. It is noteworthy that in all welded specimens, tested in fatigue, the crack was initiated at the fusion line between WM & BM2, where the fault occurred subsequently.

Table 4. Mechanical fatigue properties of the samples under study [1, 2].

Material	**$S_f = 0{,}4\sigma_{UTS}$**	**$\sigma_{fatigue}$**	***f***
	(MPa)	**(MPa)**	
BM1 A240 (304L)	259±2	218±2	0,36
BM2 A537 (I)	183±2	122±2	0,27
Butt-welded (BW)	182±2	135±2	0,30
Overlap-welded (OW)	260±2	208±2	0,32

CONCLUSIONS

Both union (butt and overlapped) steel ASTM A240-A537, ASTM A240 welded (ER-308L) and GMAW process using argon as a shielding gas, had mechanical properties that can be considered adequate to support the mechanical requirements in service, despite the relatively high values of microhardness in the HAZ, specifically near the fusion line between weld and stainless steel. By evaluating using diagrams Schaeffler, DeLong, and WRC was estimated cracking free the junction between the 304L and 308L stainless steels as well as the possibility of cracking between the structural steel A537 (I) butt and overlaps soldier the ER-308L stainless steel. Mechanical characterization will complement the by axial fatigue tests and fatigue cracked specimen, focus on determining the speed of crack propagation, and develop a mathematical model to compare with experimental results.

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