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THE EFFECT OF THE NUMBER OF WELDING PASSES IN THE ANGULAR DISTORTION OF 304L STEEL PLATES USING GMAW

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Abstract. *The use of stainless steel is gaining more space due to its excellent corrosion resistance, surface finishing, conformation capability and weldability. In the industry it is found in various applications such as pipes, tanks, reactors, distillation columns, heat exchangers and condensers. One of the problems encountered in welding is the distortion caused by the heating and cooling process located in the welded piece. The distortion causes great economic losses because it makes impossible to assemble welded structures and it makes unwanted changes in the geometry structure parts. However, the level of distortion caused in a welded structure depends of several factors. In this way, a study on the influence of the number of welding passes, in a welding joint, on the distortion degree and the bending angle using the MAG process in 304L stainless steel plates. The results showed that the number of passes made to form the weld bead has an influence in the distortion level of the structure piece.*

Keywords: *Angular distortion, 304L, GMAW*

1. INTRODUCTION

As Brazilian offshore and naval industry are growing, specially with the new pre-salt oil and gas reservoirs discovered, it is expedient to increase the exploration and prospective fleet to start using this oil. The fabrication of new drillships, FPSO's, oil tankers and other supply vessels is something that is already on going (Rocha, 2014) and independent of the kind of ship or its purpose the use of steel is a must due its resistance requirements. Using different kinds of steel demands some fabrication processes that need to be corrected measured. One of these processes is the welding that has its advantages, applications and limitations. According to Shen (2013), the cost to correct welding distortions related to the total fabrication cost can be up to 30%. The welding distortion causes variances in the structures, decreases dimensional accuracy and the load capacity of the vessels. This distortion problem is also observed in the stainless steel that has many advantages in relation to standard carbon steel, like the corrosion resistance. This characteristic makes the stainless steel a good choice for several offshore applications, but it has a higher cost. Austenitic stainless steels in an offshore environment are largely used (Wika, 2012) and due to its high cost if the structures built with those materials get welding distortions the losses will be very high. In this way to understand the factors that mostly influence the distortions due welding process is of utmost importance. The objective of this study is to evaluate the influence of the number of welding passes, in a welding joint, on the distortion degree and the bending angle using the MAG process on 304L stainless steel plates.

1.1 AUSTENITIC STAINLESS STEEL

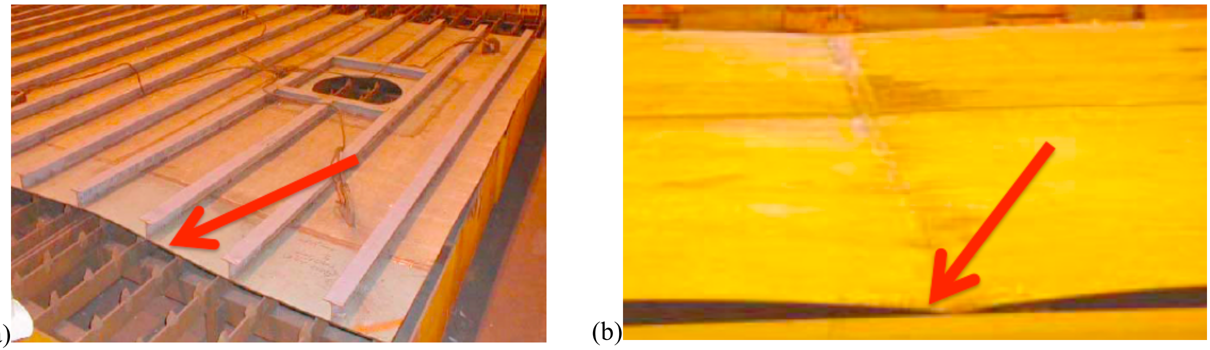
Austenitic stainless steels have a single-phase, face-centered cubic (fcc) structure that have excellent corrosion resistance. This structure is obtained from a balance of alloying additions that stabilize the austenite phase using elements such as nickel, chromium, manganese, and nitrogen. Generally the amounts of chromium ranges from 16% to 26%, the Ni can reach up to 35% and of Mn up to 15%. The 3xx series contains large quantities of nickel and up to 2% of manganese. Molybdenum, copper, silicon, aluminum, titanium and niobium can be added to the steel to grant certain specific characteristics such as being resistant to pit corrosion or oxidation. These steels are essentially non-magnetic and can be hardened only by cold working. (ASM, 1990)

The 304 stainless steel is a steel variant of the 302 with a smaller amount of carbon and more chrome. This steel has 0.08% carbon, 18.0 to 20.0% of chromium and nickel amounts from 8.0 to 11.0% manganese percentages is up to 2.0% at maximum and Silicon up to 1.0%. The 304L Stainless Steel has mechanical properties slightly inferior to 304.

The use of the letter L (Low) beside the 304L indicates that the alloy content is at most 0.03%. This lower level is used when the carbon material will be welded. The lower carbon content helps prevent the precipitation of chromium (chromium carbide forming in the weld area) and thus ensuring a minimum of 11% chromium and the possibility of forming a passive film to the stainless steel that provides corrosion resistance. (AKSTEEL, 2007)

1.2 WELDING DISTORTION

Distortion is a change in shape and dimensions that welded components suffer as a result of the material movement that occurs as a function of thermal stresses developed during the welding process. Plastic deformation results in lasting change in the component dimensions and distorts the structure (Sorkhabi, 2013). In Fig. 1 (a) it is possible to see some geometric imperfections in a stiffened panel of a semi-submersible platform. Figure 1 (b) shows a typical problem of angular distortion on a panel of a drillship.



(a) (b)

Figure 1. (a) Geometric imperfection in a stiffened panel of a semi-submersible plataform. (b) Typical angular distortion problem on a drillship panel.

The distortion in the welding process results from the expansion and contraction of the welding metal and the base metal during the heat cycle (heating and cooling). During heating and cooling, different factors influence the metal contraction and cause distortion as well the change of the physical and mechanical properties due to the heat input applied. These changes even affect the flow and uniform distribution of heat, the latter being the most important cause of deformation during welding (FBTS, 2003). Among the factors that affect the distortion there are: The restriction degree, assembling procedure, welding procedure, welding joint project, base metal properties, welding energy, internal tension of the material, welding sequence, among others.

During the welding process, the heating causes a higher thermal expansion of the upper region of the material and consequently its distortion. At the end of welding, with the cooling of the material in the weld region, the contraction occurs. As the upper part of the welded region was the most heated and may have suffered greater deformation, the material now has a final distortion facing the opposite direction of the maximum transient distortion.

There are several measures that can be taken place to reduce distortion on welded joints. Souza (2011) divides these methods into three groups in which they are actually in what phase of the welding process the distortion reduction measure will be adopted. First during the welding joint project, during fabrication and after welding (to correct the distortion). To make defect free welding it is necessary to determine the parameters and variables before the wire deposition. So it is necessary, under certain conditions, that the welding procedure to be qualificated, as well as, which method of reducing distortion should be used during the production.

2. EXPERIMENTAL PROCEDURE

The material chosen for this work was the austenitic stainless steel AISI 304L with a thickness of 9.5 mm. The methodology for this work consisted in performing multipasses welding in two filling conditions. First a root pass plus one filling pass and second condition a root pass plus two filling passes. Each one of the conditions was parameterized.

The weldings were performed on each one of the passes so that the adjustment of the parameters would produce a visually good welding fillet (good surface finish and free of surficial defects). It was used the ER308L (21% Cr and 10%Ni) as the filling material, the use of this wire electrode is found in the literature described by Modenesi (2001). The shielding gas used for the welding mixture was Ar + 2% O2 selected according to the recommendation of Scotti (2008). The conduction of the welding torch was performed by a robot model HP20D from Motoman. Figure 2 shows the dimension of the testing speciments. In order to prevent bending and to restrict movement of the test plates during the welding, a support was designed to fix the plates in place. In Fig. 3 the design is shown.

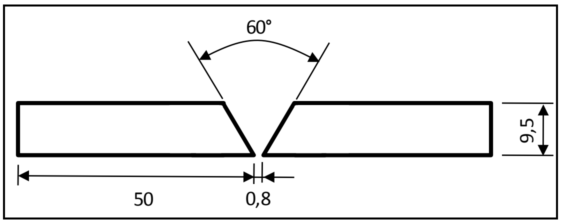


Figure 2. Specimen's dimension (mm)

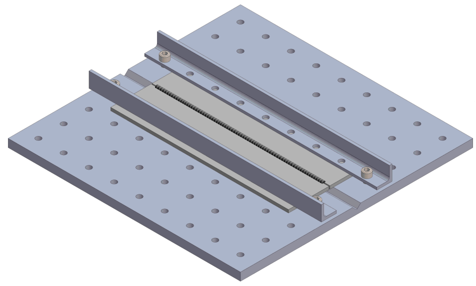


Figure 3. Test plates fixation support design

In order to visualize the material homogeneity, its distribution, possible failures in the welding process and also the weld bead dimensions, a metallographic preparation was performed on the specimens. The samples were cut, sanded and submitted to a Villela chemical reagent (5 ml HCl + 2gr Picric Acid + 100ml of Ethyl Alcohol).

2.1 MEASUREMENTS WITH THE COORDINATE MEASURING MACHINE

In order to quantify the level of distortions resulting just from the welding process, it took two sets of measurements for each sample. The first set of measurements was done prior to the welding process, with two plates to be joined only tacking the ends and center. The second set of measurements was made after the plates have been welded. At the end, the results of displacement Z of the second set of measurements were subtracted from the first set of measurements. Since the X and Y positions are the same in both conditions.

This first set of measurements identifying bending problems and misalignment of the plates before welding, making these initial conditions to be subtracted from the final result of the distortion. As for the second set of measurements, after the welding the plates were kept in a controlled environment room for 24 hours at a constant temperature of 20 °C.

To start the measurements, the welded plates were marked in three points, as shown in Fig. 4. This three points define a reference surface on the machine indicating Z = 0. These marks are for the reference surface before and after the welding procedure takes place so they are the same or very close, minimizing measurement errors. For the measurements, a mesh points with the XY position defined in the programming of the coordinate measure machine table must be created, as shown in Fig. 5. The grid is defined 15 x 4 mm on one side and in the other side of the weld bead with 12 mm distance in the X direction and 11 mm in the Y direction. These measurements are performed on the bottom plate or side opposite to the welding, avoiding so regions with the welding process spatter.

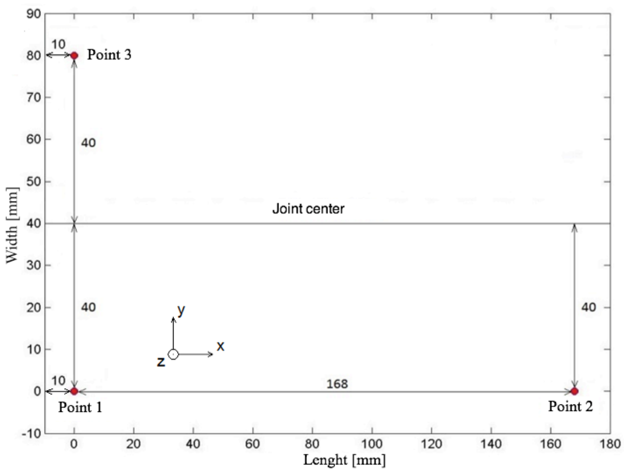


Figure 4. Reference points for the coordinate measure machine

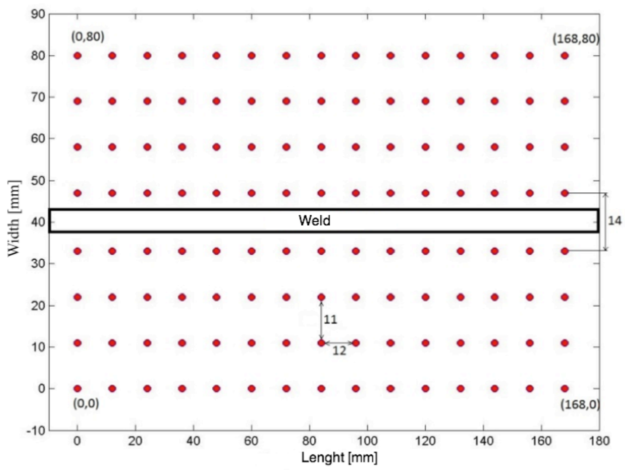


Figure 5. Mesh of points for measurement

The equipment used for the distortion measurements was a Hexagon coordinate measure machine table with CNC commands and resolution of 1 micrometer. It also used a probe with a 3 mm spherical tip.

2.2 WELDING PROCEDURE

Welds were made in stainless 304L steel plates with and without restriction under the conditions of a root pass + 1 filling pass and a root + 2 filling passes. In each condition three specimens were analyzed giving a total of 12 specimens. The welding energy measured during the welding procedures is shown in Tab.1, were V is the voltage, I is the current, v is the velocity of the welding and E is the welding energy.

Table 1. Welding energy values obtained

		Root			Filling 1			Filling 2			E [KJ/mm]
		V [V]	I [A]	v [cm/min]	V [V]	I [A]	v [cm/min]	V [V]	I [A]	v [cm/min]	
304L	Root + 1 pass	16.6	155	25	27.5	253	18	-	-	-	489.4
	Root + 2 passes	16.6	153	25	24.3	230	29	24.2	230	29	486.2

For measurement of the angular distortion it is necessary to apply a transversal cut in the weld bead and using the elementary line equation, as shown in Eq.1 it is possible to have the angular coefficient to calculate the actual distortion. In the Eq.1 y is point 1 in the coordinate axis, y_0 is point 2 in the coordinate axis, m is the angular coefficient, x is point 1 in the abscissa axis and x_0 is point 2 in the abscissa axis.

$$y-y_0=m(x-x_0) \tag{1}$$

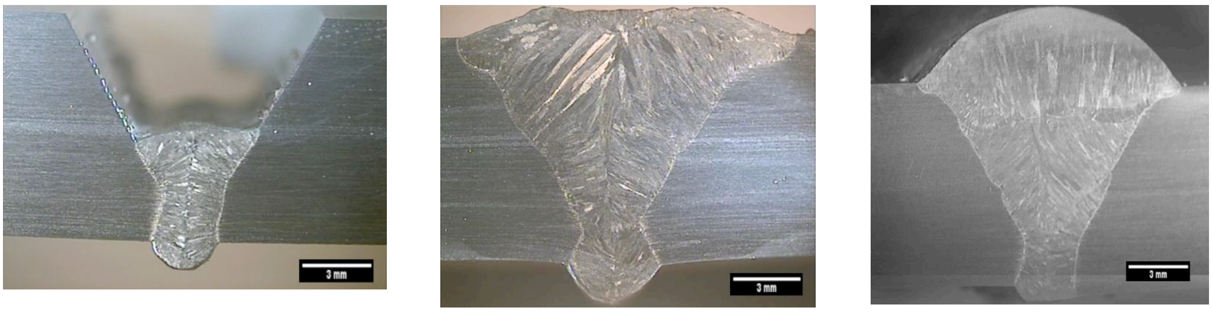
The angular coefficient m also known as a line declivity is a real number that express the trigonometric tangent of its inclination. From this definition and using Eq.1 we have Eq.2 as follows were α is the line declivity angle.

$$\alpha=\arctan\left((y-y_0)/(x-x_0)\right) \tag{2}$$

3. RESULTS AND DISCUTION

To parameterize the weldings, tests were performed and they were important to check the quality of the welded joint. A visual analysis of the macro-structure of the heat-affected zone was performed to verify the homogeneity of the material, its distribution and nature of possible failures and welding quality to the 304L plates.

In Fig. 6 the cross-sectional macrographies are shown for the root welding pass, root welding pass + 1 filling pass and root welding pass + 2 filling passes. It was performed a visual inspection and no internal defects were found.



(a) Root welding pass　　(b) Root welding pass + 1 filling pass　　(c) Root welding pass + 2 filling passes

Figure 6 - The cross-sectional macrographs of the welded samples

3.1. MEASUREMENT – 304L – ROOT WELDING PASS + 1 FILLING PASS – NO RESTRICTION

After welding the testing plates, measurements of their pre-established reference points were performed using the coordinate measurement machine. In Fig. 7 it is shown the distortion measurements prior to the welding. Figure 8 shows the measurements generated after it was performed the procedures for the root welding pass + 1 filling pass with no restriction. In Fig. 9 it is shown the actual measurement subtracting the welding measurement with the initial measurement without welding the plate.

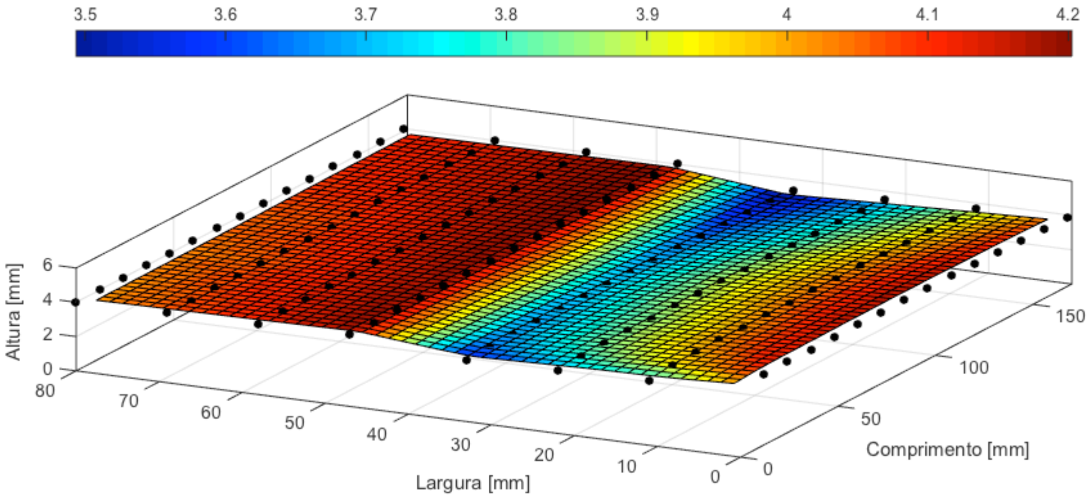


Figure 7. Distortion Measurement prior to the welding

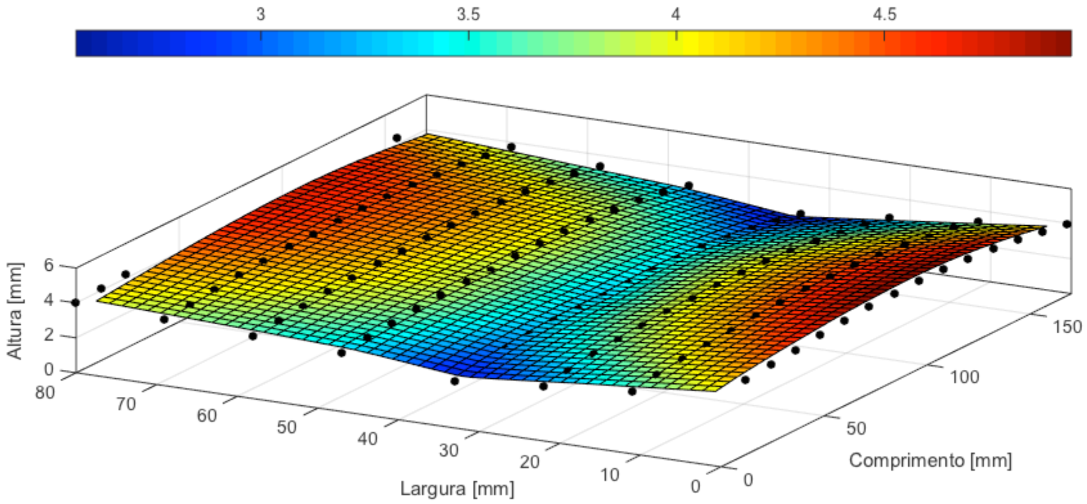


Figure 8. Measurements generated after the root welding pass + filling pass without restriction

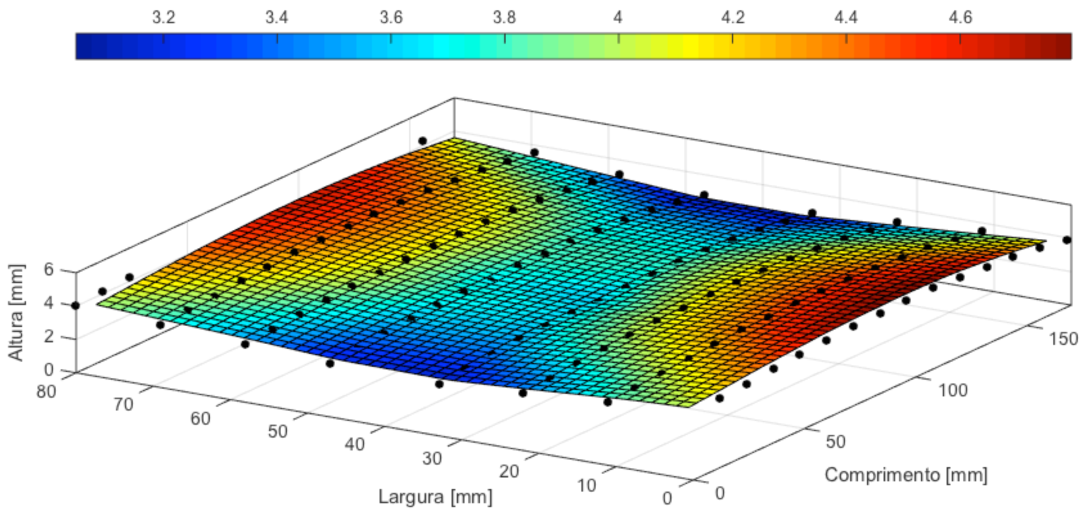


Figure 9. Actual measurement subtracting the welding measurement with initial measurement

For identification of the angle angular distortion 5 cross section cuts were performed at the intermediate points as seen in Fig. 10.

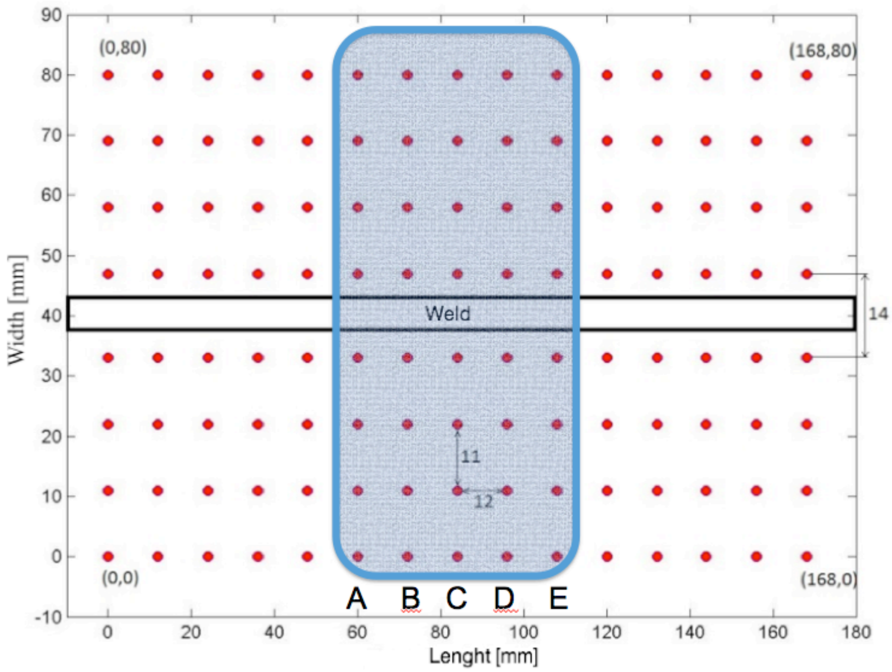


Figure 10. Identification of the 5 cross section cuts performed

In Fig.11 it is shown the cross section cuts of the actual measurement to identify the angle of the angular distortion to the condition of root welding pass + 1 filling pass without restriction.

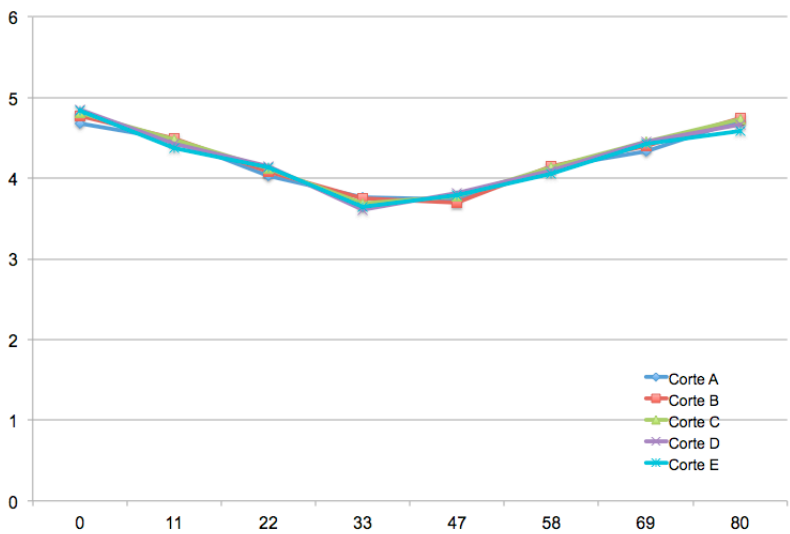


Figure 11. Cross section cuts of the actual measurement

The actual measured cross section cut values are shown in Tab. 2.

Table 2. Cross section cut values [mm]

Cut A		Cut B		Cut C		Cut D		Cut E	
X	Z	X	Z	X	Z	X	Z	X	Z
0	4.683	0	4.772	0	4.810	0	4.848	0	4.836
11	4.480	11	4.493	11	4.474	11	4.428	11	4.370
22	4.033	22	4.077	22	4.121	22	4.150	22	4.139
33	3.761	33	3.750	33	3.689	33	3.610	33	3.646
47	3.731	47	3.693	47	3.778	47	3.821	47	3.791
58	4.135	58	4.153	58	4.131	58	4.096	58	4.049
69	4.338	69	4.401	69	4.450	69	4.456	69	4.425
80	4.725	80	4.740	80	4.725	80	4.667	80	4.592

With the measured values in Fig. 9 the angle obtained is 1.76º ± 0.25 for the angular distortion. This value is calculated using Eq. 3 taking the mean of the 10 lines obtained by the 5 cross section cuts. Each of the angles are shown in Tab.3.

Table 3. Angular distortion angles obtained

	Angle	
Cut A	1.60º	1.72º
Cut B	1.78º	1.82º
Cut C	1.95º	1.64º
Cut D	2.15º	1.47º
Cut E	2.07º	1.39º
Mean	1.76º	
Standard deviation	0.25º	

3.2. MEASUREMENT – 304L – ROOT WELDING PASS + 2 FILLING PASSES – NO RESTRICTION

Following the same procedure the angle obtained is 3.61º ± 0.10º for the angular distortion. This value is calculated using Eq. 3 taking the mean of the 10 lines obtained by the 5 cross section cuts. Each of the angles are shown in Tab.4.

Table 4. Angular distortion angles obtained

	Angles	
Cut A	3.50º	3.71º
Cut B	3.60º	3.71º
Cut C	3.68º	3.73º
Cut D	3.63º	3.58º
Cut E	3.57º	3.40º
Mean	3.61º	
Standard deviation	0.10º	

3.3. MEASUREMENT – 304L – ROOT WELDING PASS + 1 FILLING PASS – WITH RESTRICTION

Following the same procedure the angle obtained is 0.32º ± 0.18º for the angular distortion. This value is calculated using Eq. 3 taking the mean of the 10 lines obtained by the 5 cross section cuts. Each of the angles are shown in Tab.5.

Table 5. Angular distortion angles obtained

	Angles	
Cut A	0.26º	0.57º
Cut B	0.20º	0.57º
Cut C	0.14º	0.48º
Cut D	0.10º	0.38º
Cut E	0.18º	0.31º
Mean	0.32º	
Standard deviation	0.18º	

3.4. MEASUREMENT – 304L – ROOT WELDING PASS + 1 FILLING PASS – WITH RESTRICTION

Following the same procedure the angle obtained is 1.39º ± 0.25º for the angular distortion. This value is calculated using Eq. 3 taking the mean of the 10 lines obtained by the 5 cross section cuts. Each of the angles are shown in Tab.6.

Table 6. Angular distortion angles obtained

	Angles	
Cut A	1.60º	0.90º
Cut B	1.68º	1.07º
Cut C	1.60º	1.27º
Cut D	1.49º	1.46º
Cut E	1.36º	1.49º
Mean	1.39º	
Standard deviation	0.25º	

3.5. COMPARITION OF THE ANGULAR DISTORTION FOR THE 2 WELDING CONDITIONS AND CHANGING THE RESTRICTION

The distortion angle values obtained for all the 304L stainless steel welded conditions studied in this paper are shown in Tab. 7.

Table 7. Angular distortion values obtained by various conditions

	Without restriction	With restriction
Root welding pass + 1 filling pass	1.76º	0.32º
Root welding pass + 2 filling passes	3.61º	1.39º

Observing the distortion values obtained for the 304L stainless steel it is possible to verify that the distortion levels were higher for welding processes where there was no restriction. The condition of the root welding pass + 1 filling pass has the lowest distortions compared with the root welding pass + 2 filling passes. For the same amount of welding energy it is possible to see that the number of passes influences considerably the weld plates distortion. As stated by Salleh (2011), the welding distortion is affected by the amount of energy given to the welding process. Angular distortion is

4. CONCLUSION

For the conditions and parameters used in this study, it is possible to conclude that:

As the arc welding processes have an intense heat input in the welding structure, the end result could not be different from the appearance of distortions and residual stresses. However, this study showed that for greater restrictions levels, lesser would be the amplitudes of these distortions.

Another condition that showed a decrease of distortion was the amount of welding passes to fill the joint. The conditions for the three welding passes showed a significant increase compared to the two welding passes condition. This result was conditioned to the same amount of welding energy for both cases, in order to take the influence of heat distortion imposed.

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6. RESPONSIBILITY NOTICE

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