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Evaluation of Residual Stress Field by X-Ray Diffraction using the Sen²? Method on E308l Stainless Steel Weld Overlays

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Abstract

The application of metal coatings by welding of steels and alloys resistant to corrosion is an alternative quite reasonable economically facing the manufacturing of solid components in these alloys. However there is a lack of information about the mechanical / metallurgical changes caused by thermal cycles of welding due to the application of these coatings, especially about its influence on the level of residual stresses, that it is essential to understand the phenomenon of stress-assisted corrosion. The aim of this study was to evaluate the level of the superficial residual stresses in coatings of AWS E308L T-1 stainless steel applied by the FCAW process on steel plates of ASTM A36. The measurements of residual stresses were performed by a portable X - ray diffractometer on the surface of the coatings and the main results obtained were that the nature of residual stresses on the surface of the coatings always showed compressive and it was not observed linearity of the magnitude of the residual stresses as a function of the welding heat input.

Index terms— welding, stainless steel, residual stress, x-ray diffraction.

1 Introduction

lobal economic pressures and characteristics of national producing basins have increasingly led refineries use heavy oil in their processes. This requires the materials used in plant of exploration and processing of oil and its derivatives excellent corrosion resistance and good mechanical properties [1]. Among these metallic materials stainless steels and nickel super alloy scan be highlighted [2,3,4]. However, the manufacture of solid components using these alloys makes them uneconomical equipment. Therefore, a viable alternative to such a problem is the application of metallic coatings by welding of these alloys on structural and piping carbon steel [5].

However, the welding of dissimilar materials leads to rise residual stress level due to difference between coefficients of thermal expansion and contraction [6,7]. It is well known that the welding residual stresses have very significant influence on the fatigue life, crack growth, acceleration (or retardation) of corrosion processes assisted by tension and other effects [8,9,10].

In this context, this study aimed to evaluate the level of residual stresses in surface coatings of stainless steel E308L T1 applied by the FCAW process in plates of ASTM A36 steel.

2 II.

3 Materials and Methods

4 a) Base Metal and Consumables

In this paper ASTM A36 steel was used as the base metal and the AWS E308L T1 with a diameter of 1.2 mm as filler metal. Table 1 shows the chemical composition of the materials used according to the manufacturer. The welds were made by FCAW (Flux Core Arc Welding) process. An electronic welding source and a system of data acquisition for control of welding parameters was used. The welding procedure was performed without restriction and without weaving. The specimens consist of three weld beads deposited in the Author ? ? ?: Universidade Federal De Campina Grande -UFCG, Departamento De Engenharia Mecânica, Aprígio Veloso, Cx., Campina Grande, PB. e-mails: raphael.engmec@gmail.com, santos@dem.ufcg.edu.br, theo@dem.ufcg.edu.br flat position by varying the voltage (U), the wire feed speed (Fr) and travel speed (Ts) generating different values of heat input (H). The values of the welding parameters used in the experiments are shown in Table 2. Un overlap of 1/3 weld beadwidth was used as illustrated in Figure 1. Inclination of the welding torch (? = 15° to the vertical), welding direction "pushing" mode current with reverse polarity CC+ and contact tip away from the workpiece of 15 mmhave been kept fixed. The stress analysis was performed on the surface of the coatings using a portable X-ray diffractometer (Figure **??**). From these graphs, it is noted that the central region of the coatings is more compressive than the periphery, and that the residual stress field develops compressive values in the top coating with decrease and increase again at the end of coating. Results from the literature [12,13] indicate that the 18-8 alloys (% Cr-% Ni) show higher variation of the residual stresses along the width of the weld bead. These fluctuations indicate that the residual stresses are not constant in the irradiated areas.

Figure **??** (a) shows that the maximum value of longitudinal residual stress was about 700 MPa in modulus in region 2 at the end of the coating. The minimum value in modulus was 200 MPa, in the beads 1 and 3 through the coating. Figure **??** (a) shows that the transverse residual stresses are smaller in magnitude than the longitudinal. The maximum transverse residual stress was 380 MPa, compared to 700 MPa (longitudinal residual stresses) in the same region.

It can be seen from the Figure **??** (a) the presence of residual tensile stresses at the beginning and middle of the coating bead, subsequently evolving into a state of compressive stress at the end of the coating. Bezerra et al. [14] hypothesized that welding defects such as discontinuities and lack of fusion of the weld metal can contribute to justify the presence of these tensile stresses in these regions.

Figures **??** and 9 show a distribution of the residual stress field similar to previous coatings, although the magnitude of the residual stress values due to the change significantly greater amount of welding energy with which these coatings were applied. Cardoso [15] found that joints subjected to different welding energies have similar distribution of residual stress on the surface, but may have different magnitudes of stresses.

The nature of the distribution of residual stress is closely linked to the nature of electric arc welding characteristic of each process [16].

Table 3 shows the average values of longitudinal and transverse residual stresses and their deviations and coefficients of variation. 3 gives an idea of the magnitude of the average longitudinal and transverse residual stresses in the coatings. It is noteworthy that the transverse residual stresses values had lesser magnitude than the longitudinal residual stress, corroborating the results of KOU [7]. All coefficients of variation (CV) are observed near 0.3; as criteria for acceptance in this work it was established that values lower than 0.5 CV are needed to express the average representative form, and CV values close to 0.3 are considered optimal.

The nature of the average residual stresses in the coatings was compression, however, it was observed during the individual analyzes some tensile residual stresses value, indicating the probable presence of welding defects. The compressive nature of the stresses in these coatings can be explained due to a physical characteristic of the filler metal involved. During the process of solidification austenitic stainless steel undergoes two phase transformations, the first liquid metal to ? ferrite, body-centered cubic structure, the second transformation is the ? ferrite to austenite structure which is cubic face centered. In this last phase transformation, there is an expansion of the unit cells, since the parameter of the face-centered cubic structure network is greater than the body-centered cubic [17]. This expansion opposites the nature of the substrate, which is ferritic, which tends to contract during the solidification process, combined with the mismatch between the coefficient of thermal expansion of stainless steel (17 -19 mm m-1 K-1) and the structural substrate generates compressive residual stresses on the surface of the coating [12,13,18].

Figure 10 illustrates the influence of heat input on the level of residual stresses.

Figure 10 : Influence of heat input on the level of longitudinal and transverse residual stresses, and the interaction between the stress levels in the FCAW process In this paper, the results do not indicate a linear relationship between the levels of residual stresses and the values of welding energy. This non-linearity can be attributed to competitive phenomena governed by the heat input and its directly influence the magnitude and nature of the residual stresses as:

? The the volumetric fraction of ? ferrite present in the weld metal, whose amount is proportional to the welding energy [19]. From there it can be hypothesize that the presence of ? ferrite can induce compressive residual stresses present in the weld metal; ? The size of the molten pool, where a larger restriction is imposed on the welded assemblies with lower energy, since they do not have major penetrations, which results in a large volume of all that remains solid during welding thereby increasing the restriction and consequently raising the level of residual stress;

? Welded specimens with higher heat input have a large amount of deposited material which results in high levels of residual stress.

Figure 11 shows the volumetric fraction of ? ferrite, evalueted qualitatively by the method of meshes [20]. The CP 5 coating was applied using a heat input H = 10.97 kJ / cm, this welding condition presented 23 mesh nodes on the ? ferrite. The CP 8 was applied using a heat input H = 15.99 kJ / cm with present 45 mesh nodes on the ? ferrite. In general, it can be noticed that increasing heat input occurs an increase in the the Comparing the information in Table 3 with those in Figure 11it can be noted that this increase results in a slight reduction of the longitudinal residual stresses and there is an increase of transverse residual stresses. Thus, for the range of low to medium welding heat input the magnitude of the longitudinal welding residual stress decreases with increasing welding energy due to the increased the volumetric fraction of ? ferrite present in the weld metal. However, there is a sharp increase of the transverse residual stresses.

Although it may be inferred that when the longitudinal residual stresses become less compressive the transverse residual stresses tend to become more compressive in order to keep a balance between these stresses.

IV.

5 Conclusions

? The surface residual stresses in the coatings were predominantly compressive. The central region of the coatings always showed less compression than the periphery;

? It was not observed a linear relationship between the magnitude of the residual stresses and the welding heat input due to competitive phenomena such as precipitation of ? ferrite in the weld metal and the volume of material deposited in the application of coatings using high welding heat input;

? In general, the microstructure observed in the weld metal was austenite with ? ferrite, and the volumetric fraction of ? ferrite may play a significant influence on the magnitude of the residual stresses.

V. [1]

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Figure 1: Figure 1 :

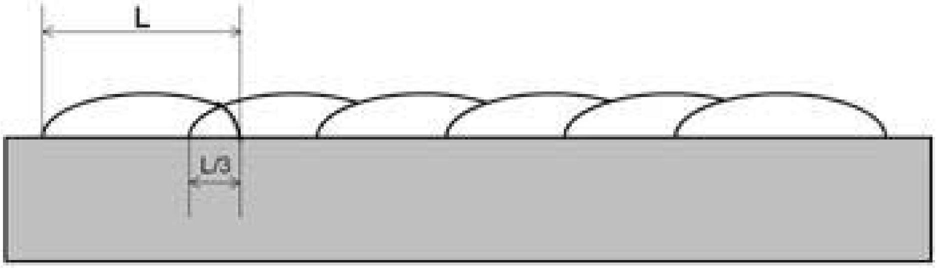

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Figure 2: Figure 2 :Figure 3 :

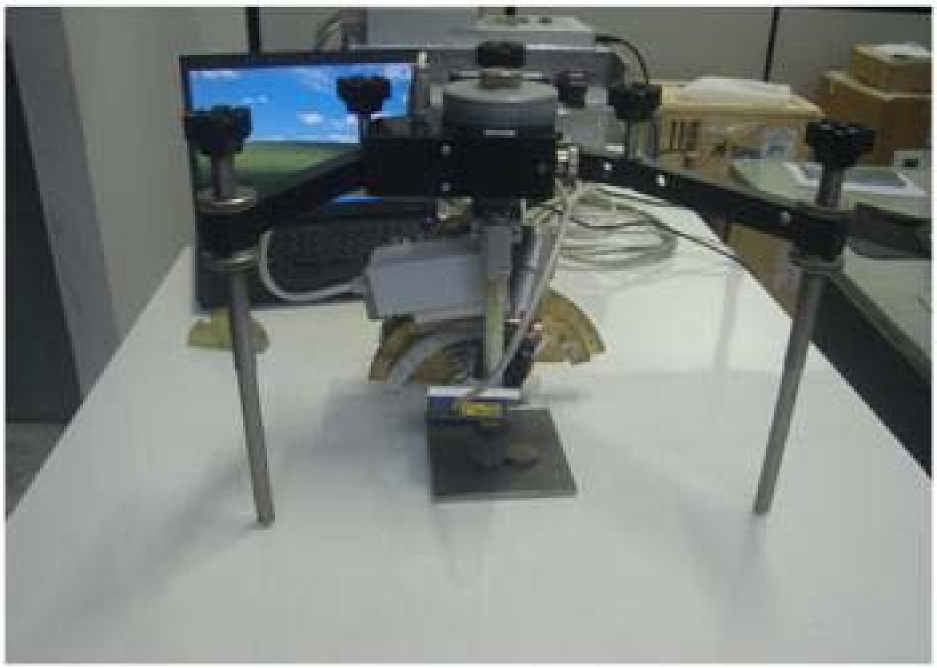
45 

Figure 3: Figure 4 :Figure 5 :

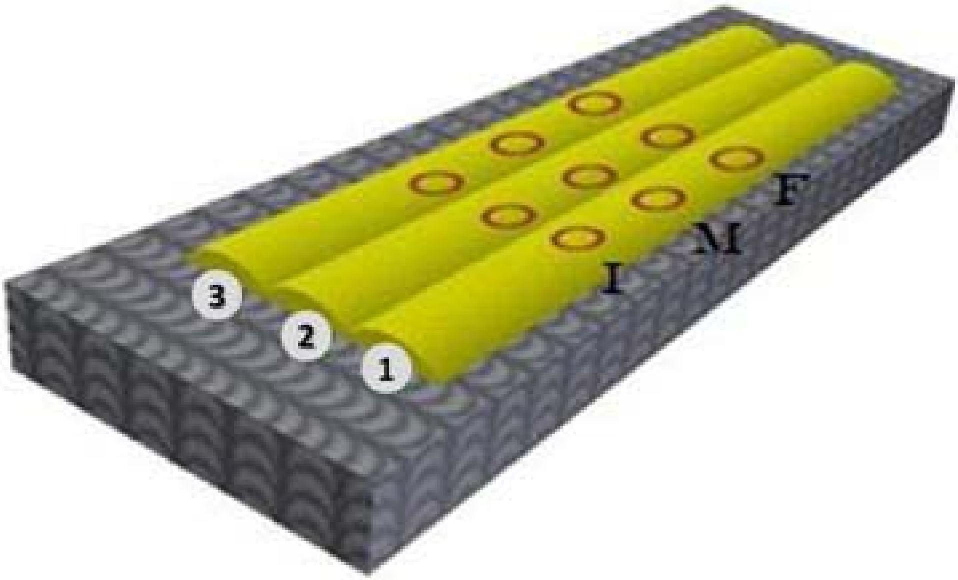
6789 

Figure 4: Figure 6 :Figure 7 :Figure 8 :Figure 9 :

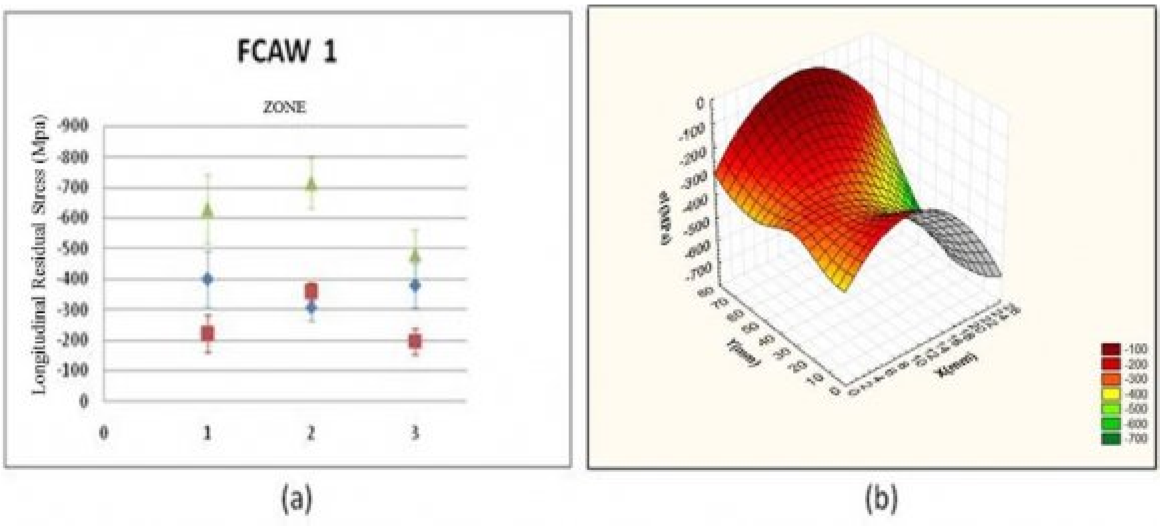


Figure 5: I

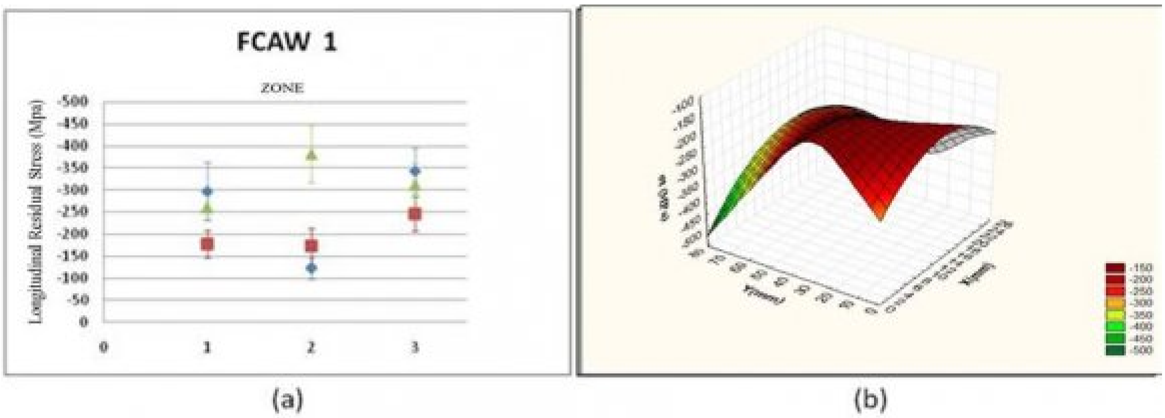


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Figure 6: Figure 11 :

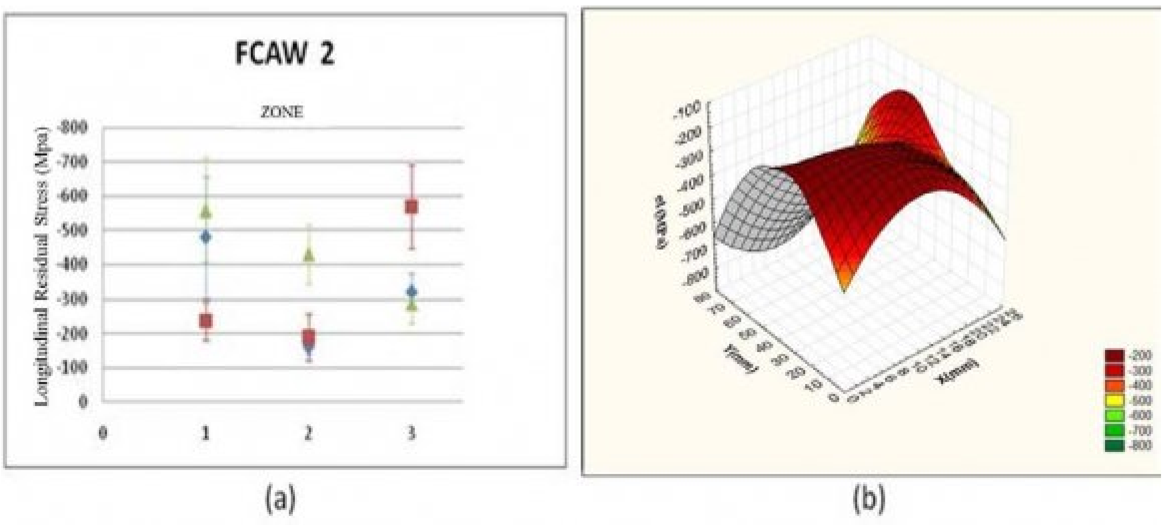

Figure 7:

1

	C	Cr	Ni	Mo	Mn	Si	Cu	P	S	Fe
AWS E-308L	0,03	19,5 -22,0 9,0 -11,0 0,75	1,0 -2,5		0,30 -0,65	0,75		-	-	Balanc
ASTM A 36	0,18-0,23	-	-	-	0,30-0,60	-	-	0,03 máx.	0,05 máx.	Balar

b) Experimental Procedure

Figure 8: Table 1 :

2

	U (volts)	Fr (m/min)	Ts (cm/min)	H (kJ/cm)
1	30,0	6,0	20,0	19,65
2	40,0	6,0	20,0	26,19
3	30,0	7,0	20,0	21,20
4	40,0	7,0	20,0	28,19
5	30,0	6,0	26,0	10,97
6	40,0	6,0	26,0	14,51
7	30,0	7,0	26,0	11,82
8	40,0	7,0	26,0	15,99
9	35,0	6,5	23,0	16,94
10	35,0	6,5	23,0	17,52
11	35,0	6,5	23,0	17,44

Figure 9: Table 2 :

3

		Longitudinal (MPa)			Transverse (MPa)	
	Average	Desviation	CV	Average	Desviation	CV
1	-410	68	0,1658	-257	44	0,1712
2	-344	88	0,2558	-233	70	0,3004
3	-373	74	0,1984	-260	54	0,2077
4	-591	143	0,2420	-278	54	0,1942
5	-494	144	0,2915	-167	63	0,3772
6	-498	110	0,2209	-286	53	0,1853
7	-393	119	0,3028	-250	57	0,2280
8	-470	111	0,2362	-361	75	0,1847
9	-506	142	0,2806	-195	65	0,3333
10	-456	109	0,2390	-251	110	0,4382
11	-390	107	0,2744	-241	65	0,2697

Figure 10: Table 3 :

Figure 11: Table

.1 Acknowledgements

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