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EFFECT OF HEAT TREATMENT AFTER WELDING ON THE IMPACT TOUGHNESS OF ASTM A890/A890M SUPERDUPLEX STAINLESS STEEL

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Abstract. *Superduplex stainless steels are materials that have excellent mechanical and corrosion resistance properties. The ASTM A890/A890M standard steels are obtained by casting process and applied to parts with complex geometries for harsh environments. In this work, the impact toughness at temperatures of 25 °C and -46 °C in electric arc welded joints with coated electrode in the base metal and in the fusion zone were analyzed. The microstructural aspects were observed with optical and electronic scanning microscopes. The impact toughness obtained on the BM was 64 J (-46 °C)/94 J (25 °C) and on the fusion zone in the as-welded condition and post-welded heat treatment were 54 J (-46 °C)/85 J (25 °C) and 75 J (-46 °C)/122 J (25 °C), respectively. In all conditions the impact toughness was greater than 27 J, the minimum value specified by the NORSOK standard. The post weld heat treatment promoted the adjustment of ferrite/austenite phases to more equivalent proportions from 61/39 to 49/51 in the fusion zone which resulted in an increasing on the impact toughness.*

***Keywords**: Superduplex stainless steels, Impact toughness, Post welded heat treatment.*

1. INTRODUCTION

Ferrite-austenitic stainless steels (duplex and super duplex) (SSDs and SDSSs) are characterized by the combination of the ferrite (δ) and austenite (γ) phases in a ratio of 1:1 and together they promote good mechanical strength and corrosion. The equilibrium of these two phases at room temperature is a result of the action of some alloying elements that stabilize these phases (Nilsson, 1992; Pohl, Storz and Glogowski, 2007; Charles, 2008). The high mechanical strength is influenced by ferrite and corrosion resistance by austenite (Hwang and Park, 2009). The balance of these phases is obtained by chemical control (Weber and Uggowitzer, 1998; Hwang and Park, 2009) and by suitable heat treatment (Zhang *et al.*, 2017). According to NORSOK M601 (NORSOK STANDARD M601, 2008) in welded joints it is necessary to have a minimum austenite content of 30% and the Charpy impact toughness should not be less than 27 J tested at -46 °C. The impact strength decreases as the ferrite volume fraction increases. At low temperatures the ferrite absorbs little energy (Southwick and Honeycombe, 1980).

The steel analyzed in this work is regulated by ASTM A890/A890M-grade 5A. The pitting resistance equivalent number (PREN) for SDSSs is over 40 (ASTM A890/A890M, 2014). Working with these materials regularly at some point will require some soldering process, either in the joining of parts or in repairs and often the welding becomes detrimental as the unbalance of the phases δ/γ can occur. On the other hand, post-weld heat treatment (PWHT) can change the dimensions of parts or become unviable in large equipment, as in the case of equipment for oil platform.

According to the (ASTM A890/A890M, 2014) standard, heat treatments are needed after welding in these steels for repairs of more than 20% of depth or that exceeds more than 65 cm^2 in length. Therefore, we studied the as-welded and post-weld heat-treated conditions, aiming to conduct a microstructural characterization and to study if the PWHT (1140 ° C for 4h with subsequent cooling in water) influence in the impact toughness. Welded joints were conducted by coated electrodes in steels of standard ASTM A890/A890M-grade 5A.

2. MATERIALS AND METHODS

The ASTM A890/A890M-grade 5A superduplex stainless steel plates were produced in dimensions of 360 x110 x 40 mm (length x width x thickness), cast in a Vacuum Induction Melting (VIM) with a maximum power of 400 kW and frequency of 60 Hz and solidified in sand mold and followed by solubilization heat treatment to adjust the ferrite and austenite phases following the recommendations of the standard (ASTM A890/A890M, 2014).

The filler metal used for welding was AISD Zeron®100, its chemical composition as well as that of the base metal (BM) is described in Table 1. The welding process used was Shielded Metal Arc Welding (SMAW), the double V-bevel and 70-degree angle with approximately 90 welding passes, the voltage was between 20 - 25 V and the current between 100 - 130 A.

Table 1: Chemical Compositions and PREN* of ASTM A890/A890M - grade 5A and Zeron®100 filler metal (wt %)

	C	P	S	Cr	Ni	Mo	Cu	W	N	PREN*
5A	0.024	0.032	0.006	24.95	7.53	4.25	-	-	0.28	43.5
Zeron®100	0.028	0.029	0.006	25.1	8.06	4.19	0.42	0.44	0.26	43.1

*PREN = %Cr+3.3%Mo+16%N≥40 (% by weight).

After the welding procedure, the welded plates were divided into two parts and one was destined to the PWHT at 1140 °C during 4 hours with subsequent cooling in water. For microstructural and mechanical evaluation, the study region was the cross section of the weld in the BM and in the fusion zone (FZ).

The impact tests were carried out in an OTTO WOLPERT-WERKE-GMBH, PW 30 K universal test machine with a maximum capacity of 294 J. The temperatures of - 46 °C (standard temperature established by NORSOK M601 standard which regulates test conditions and quality requirements for the supply of components to offshore platforms in the North Sea) (NORSOK STANDARD M601, 2008) and at 25 °C. The specimens were prepared according to ASTM A370 (ASTM A370, 2014), 3 samples were used for each test and their dimensions were 55 x 10 x 10 mm.

In order to complement the results, metallographic examinations were carried out with sanding in the particle sizes of 220 to 1200 mesh and polishing with diamond paste of 6, 3 and 1 µm. The microstructure was revealed by electrolytic attack at 20% NaOH at a voltage of 5 V for 10 s. The volumetric fraction of the phases was obtained by color contrast using ImageJ software according to ASTM E1245 (ASTM E1245, 1999), 15 measurements were performed for the same sample. The images were obtained by light optical microscope (LOM).

3. RESULTS AND DISCUSSIONS

Figure 1 shows the typical microstructure of the base metal (BM), fusion zone (FZ) of the as-welded and PWHT conditions. Figure 1a depicts the morphology of the ferrite (blue stained matrix) and austenite phases (precipitated with rose staining) in the MB and in Figure 1b to FZ in the condition as welded presents the ferritic matrix (in brown) and primary austenite (γ) and secondary (γ_2) with white staining. The dark spots present in Figure 1a are defects originating from the casting process, such as voids and inclusions.

The secondary austenite (γ2) found in Figure 1b presents with a rounded morphology and its presence improves the strength of the welded joint, however, as this phase is formed from the ferrite removing chromium, molybdenum and nitrogen, this phase can be sensitive and localized corrosion resistance decrease (Nilsson and Wilson, 1993). In Figure 1c, γ_2 was solubilized and as final structure there is only δ and γ.

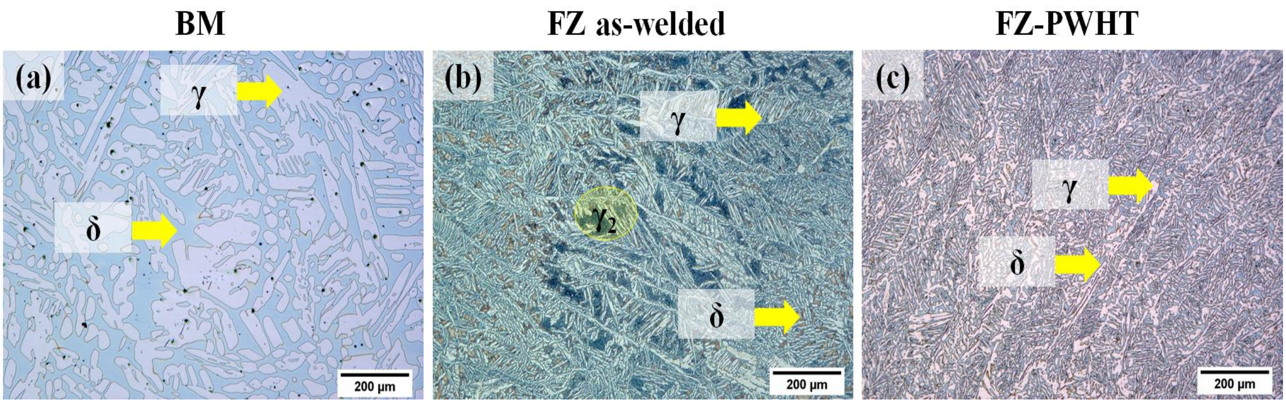

Figure 1: Microstructures: (a) BM (δ - in blue and γ- white); (b) FZ (as-welded); (c) FZ PWHT. Electrolytic attack with 20% NaOH. LOM

Figure 2a shows the results of impact toughness in which MB presented 64 J (-46 °C)/ 94 J (25 °C) and FZ in the as-welded and PWHT condition were 54 J (-46 °C)/85 J (25 °C) e 75 J (-46 °C)/ 122 J (25 °C), respectively. As shown in Figure 2b the volumetric fraction of the δ/γ phases in the BM were 59/41, in the FZ 61/39 and 49/51 in the in the as-welded and PWHT condition, respectively.

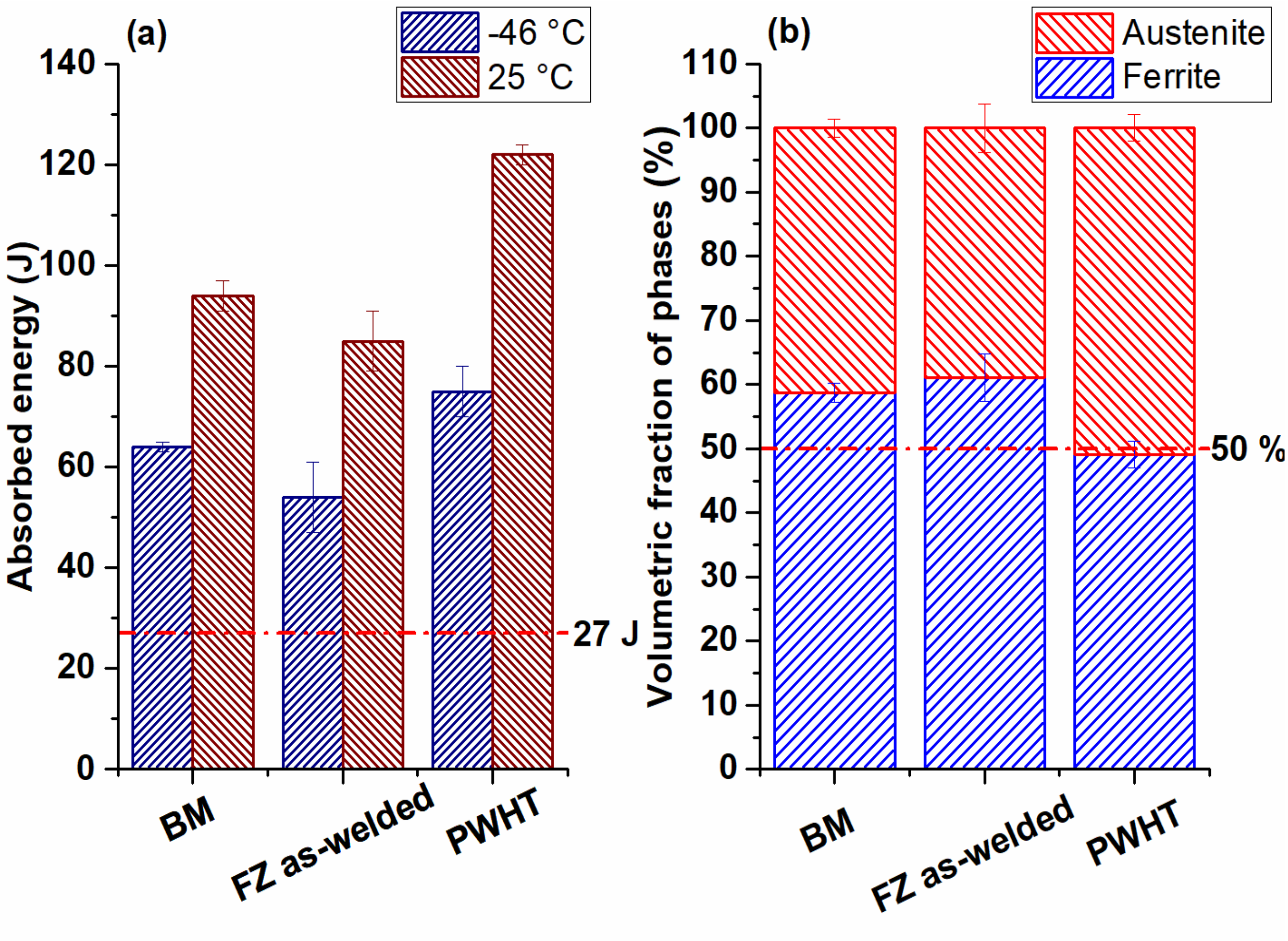

Figure 2: (a) Energy absorbed in J; (b) Volumetric fraction of the phases. In the BM and FZ regions (as-welded and PWHT)

The impact toughness is strongly related to the percentage of phases and their morphology. Figure 1a-b shows that the higher the ferrite content the lower the energy absorbed independent of the temperature tested, this can be explained in terms of crystalline structure where materials that have face-centered cubic (FCC) crystalline structure do not present ductile-brittle transition as body-centered cubic (BCC) crystalline structure. The PWHT increased the energy absorbed in the FZ same as those tested at -46 °C.

Regarding only the microstructural and mechanical aspects all the results were above the values specified by the standard for impact toughness that should be above 27 J. Although the material PWHT have presented better mechanical and microstructural properties, it was also possible to obtain good results for the steel in the as-welded condition.

Figure 3a-f shows the microstructural aspect after the Charpy impact toughness test at -46 °C and 25 °C, it is observed that even at negative temperatures the fracture was predominantly fibrous, with the presence of larger dimples in the BM and smaller in FZ. It was observed inclusions, principally in BM.

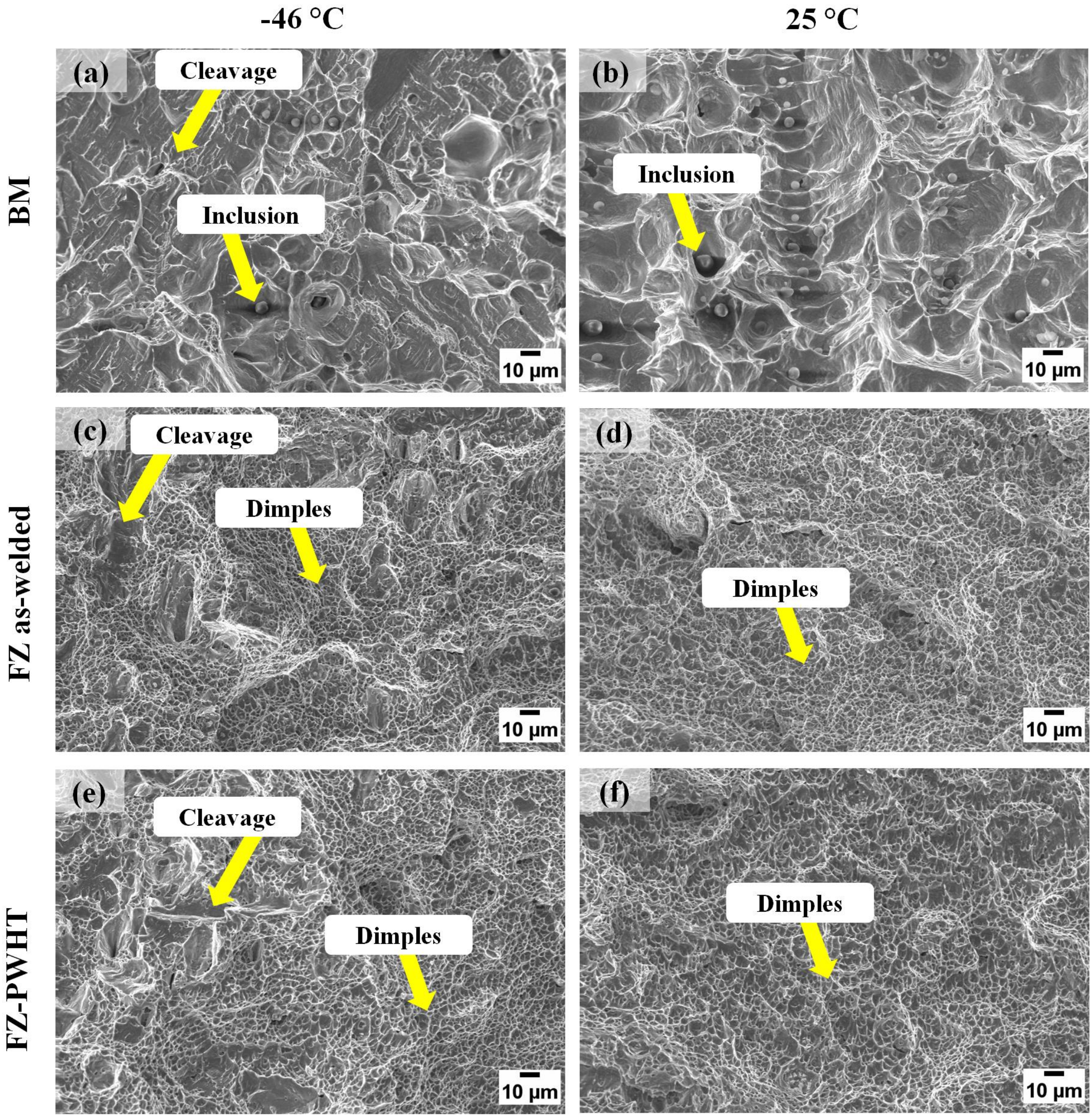

Figure 3: Fractures (a)-(c)-(e) tested at -46 °C and (b)-(d)-(f) tested at 25 °C, both in regions BM, FZ (as-welded) and FZ (PWHT). Obtained by SEM

4. CONCLUSIONS

ASTM A890/A890M-grade 5A superduplex stainless steel plates welded by SMAW using Zeron®100 as filler metal were divided into two parts. One part was submitted to PWHT (Post Weld Heat Treatment) at 1140 °C for 4h with subsequent cooling in water. The results showed that:

- The impact toughness obtained was 64 J (-46 °C)/94 J (25 °C) on the BM (Base Metal) and 54 J (-46 °C)/85 J (25 °C) on the FZ in the as-welded condition.
- The PWHT promoted the adjustment of ferrite/austenite phases to more equivalent proportion from 61/39 to 49/51 in the FZ, increasing the impact toughness to 75 J (-46 °C)/122 J (25 °C) on this region.
- In all conditions the impact toughness was greater than 27 J, the minimum value specified by the NORSOK standard.
- The fracture was predominantly fibrous, with the presence of larger dimples in the BM and smaller in FZ, even at negative temperature.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICEES

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