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EFFECT OF HEAT TREATMENT ON RESIDUAL STRESS FIELDS IN CLADDED STEEL TUBE HEADER SHEETS OF REACTOR PRESSURE VESSELS

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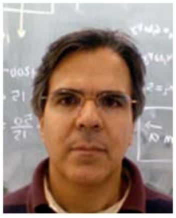


ABSTRACT

The aim of the work is to study the effect of the heat treatment temperature on the relaxation of residual stresses of the heat affected zone of cladded tube header sheets where cracking events are common. Three square pieces were removed from a plate of EN 10028-2-P355 QH carbon steel and cladded with a stainless steel filler metal, by submerged arc welding, in one of the faces. Three layers were deposited. Following the cladding process two of the three coupon plates were submitted to different post welding heat treatments: one at 620 ºC for an holding time of 1 hour and the other at 540 ºC for a period of ten hours. The residual stresses in-depth profiles were determined by neutron diffraction, before and after the heat treatment. The profiles were measured through thickness in the crest (top) and in the valley (bottom) of one welding pass.

1– INTRODUCTION

In industrial application, such as is the case of power and petroleum industries as well in chemical conversion industries, many pressure vessels require protection of the walls to resist to corrosion attack. This protection is provided by the deposition of weld overlays in austenitic stainless steels on ferritic base metal (Kumar et al. 2003; Muragan and Parmar 1997).

These overlays can be deposited by several welding processes, such as Metal Inert Gas (MIG), Submerged Arc Welding (SAW) or Electroslag Welding (ESW) using filler wires or, in the last two processes, also strip cladding, in order to get high deposition rate and low penetration depth. Despite the fact that weld cladding is carried out by various techniques, automated SAW is generally employed due to its high quality and reliability. The quality of the stainless steel cladding is very affected by the amount of dilution and the mode of solidification (Murugan et al. 1993; Chi et al. 2007).

The main problems arising from the deposition of these layers are the cracking phenomena in the interface, which affect the integrity and safety of cladded pressure

vessels (Hohe et al. 2008). The cracking mechanism is generally associated to the carbon migration taking place in the interface between ferritic and stainless steel as well to the residual stress fields induced by the welding procedure. The migration of carbon to stainless steel initiates during the welding operations and continues during post-weld heat treatment giving opportunity to the formation of complex microstructures, consisting mainly of martensite and carbides. These hard and brittle structures are very susceptible to cracking, mainly if tension stresses and hydrogen are present. Residual stresses result from the cladding procedure itself due to the dissimilarity in thermal conductivity and thermal expansion coefficients of the base and deposited materials as well to the differences in thermal cycles induced in these regions (Veiga et al. 2003; Yen et al. 1994). The objective of post-weld heat treatment (PWHT) is to reduce the residual stress level in weld metal and base material in order to dimensionally stabilize the welded zone, which needs subsequent machining, and enhance the fracture and fatigue behavior and corrosion resistance of clad walls (Tsay and Lin 1998; Chauvy et al. 2008). High PWHT temperatures have beneficial effect in terms of stress relaxation but tend to degrade the metallurgical properties of the clad zone.

The aim of the work is to study the effect of the heat treatment temperature on the relaxation of residual stresses of the heat affected zone, where cracking events are common.

The residual stresses induced by welding have received increasing attention in the pressure vessels and piping research community due to the application of modern structural intensity assessment procedures for defective welded components, which require more accurate information on the weld stress state, to give a more realistic assessment (Bouchard 2007). Effectively, the accurate quantification of the magnitude of residual stresses in welded joints is a challenging task (Bouchard 2008) and nowadays there are only few new proposals but not yet well-established methods (Withers et al. 2008). However, and independently of the future success of these new procedures, the experimental evaluation of the residual stresses profiles by using processes such as the neutron diffraction is still the more effective and realist way of characterizing the welded surfaces (Price et al. 2008).

2– MATERIALS AND TECHNIQUES

A EN 10028-3 - P355 NH carbon steel plate of 300 x 300 x 20 mm was cladded by submerged arc welding (SAW) in one of the faces, using a filler metal of 4 mm in diameter. Three successive layers were deposited in the surface of coupon plate. An EN 12072 – S 23 12 2 L electrode was used in the first layer, in order to minimize metallurgical problems, whereas an EN 12072 – S 19 12 3 L electrode was used in the second and third layers. During welding, specimens were constrained in order to prevent coupon plate distortion. This procedure allowed the production of welded specimens with a final thickness in the order of 27,5 mm. The composition of the base material and the filler metals is listed in Table 1. The parameters of the SAW process are indicated in Table 2.

Subsequently the cladding process three square pieces of 150 x 150 mm were removed by electrical discharge machining from the carbon steel plate. Two of the three coupon plates were submitted to PWHTs, one at 620 ºC for an holding time of 1 hour (sample HT620) and the other at 540 ºC for a period of 10 hours (sample HT540).

The residual stress analyses were performed by neutron diffraction at FRM II, Technische Universität München (TUM), on the STRESS-SPEC instrument (Fig. 1). This diffractometer is located at the thermal beam port SR3 and it is dedicated to texture and residual stress analysis (Hofmann et al. 2006). A PSD area detector of 20 x 20 cm^2 collected the diffracted radiation. The setup may use

three different monochromators: Ge (511), bent silicon Si (400) and pyrolitic graphite (002). The selection of monochromators and the possibility to vary automatically the monochromator take-off angles from $2\theta_M = 30º$ to 120º allows finding a good compromise between resolution and intensity for each measuring problem. The measurements are performed around a scattering angle of $2\theta_S \approx 90º$. The gauge volume defined by the optical system of primary and secondary slits (ranging from 0.5 x 0.5x 0.5 mm^3 to 5 x 5x 20 mm^3) is designed with regard to reproducibility of geometrical alignment. Both slit systems are linked to the sample table and the detector in such a way that the center of the beam remains the same under all conditions. Therefore new alignment will not be necessary even in case the wavelength or the slit to sample position has been changed.

Table 1 - Composition of base material and filler metals.

Material [%]	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
EN 10028-3 P355 NH	0,18	0,33	1,12	0,015	0,002	0,04	0,16	-	0,21	0,004
EN 12072 S 23 12 2 L	0,008	0,29	1,4	0,016	0,003	21,3	14,8	2,57	0,11	0,057
EN 12072 S 19 12 3 L	0,018	0,38	1,8	0,016	0,009	18	11,7	2,54	0,07	0,055

Table 2 - SAW parameters

Pre-heating	by flame (150 ºC)				
Amperage	300 A				
Voltage	29-30 V DC (+) 30 m/h				
Flux	Avesta Flux 801 - composition [%]				
	SiO_2	MgO	CaF_2	Al_2O_3	Cr
	31.0	25.0	6.0	13.0	4.8

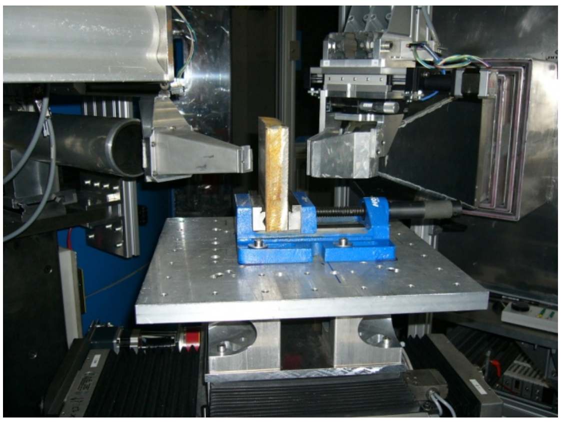
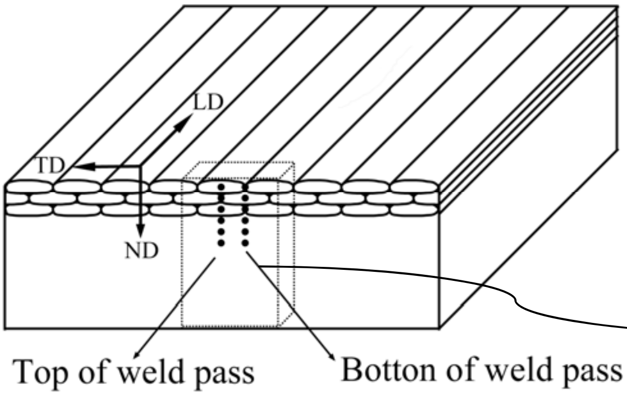


Fig.1 - STRESS-SPEC instrument for stress and texture analysis by neutron diffraction, at FRM II – TUM, Germany.

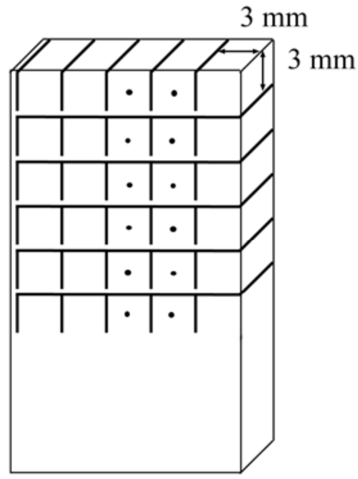
In order to evaluate the residual stresses by neutron diffraction, the strains in the bulk must be measured in three directions assumed to be the principal

stress directions as inferred from the weld geometry (Hauk 1997). The residual strain data were acquired in the three orthogonal directions (longitudinal, transverse and normal to the welding direction, shown in Fig. 2), which enabled the determination of the residual stresses. The quantification of the stress free lattice spacing, d_0, was evaluated by neutron diffraction acquisitions in 6 small cubes in each specimen, cut by electro-discharging machining, following the scheme in Fig. 2-b. The first three cubes correspond to the welding layers and the others to the base material.

The residual stresses in-depth profiles were determined in the central point and in the border of one weld pass (*top* and *bottom*, as shown in Fig. 2-a). For each depth profile approximately 10 points in depth were selected for austenitic phase (weld metal) and 14 points for ferritic phase (base metal). This procedure was applied to the three samples: as-welded sample (AW) and heat-treated samples (HT620 and HT540).



a)-



b)-

Fig. 2- a)- Definitions of the measuring directions: LD, TD and ND, which correspond to longitudinal, transverse and normal direction of welding; b)- Specimen for the determination of the stress free lattice spacing, d_0, of the samples.

3- RESULTS AND DISCUSSION

In this document are presented the results of the residual stresses obtained in the longitudinal direction of the weld layers. The profiles of residual stresses measured through thickness in the crest (top) and in the valley (bottom) of the as-welded sample (AW) are displayed in Fig. 3. Tensile stresses are installed in both regions of the deposited weld metal, though some discrepancies can be observed in the magnitude of the stresses. It was observed a maximum of + 200 MPa at 3 mm depth in the top region, whereas a maximum of + 500 MPa was observed in the bottom at the first 4 mm depth.

The HT540 sample presented some increase in the residual stress level at the crest (≈ + 450 MPa), close the surface of the layers, as opposed to the weld valley (- 350 MPa), where a change from tensile to compressive stresses was observed, as illustrated in Fig. 4. However, the analysis made in the HT620 sample does not show the same evolution, as displayed in Fig. 5. In this sample compressive residual stresses were observed close the weld surface, both in the top and in the bottom regions; although tensile residual stresses remain in a region beyond the 2 mm depth.

The samples presented a very large grain size which contributed for experimental problems at diffracted

acquisitions. In fact, for several directions, several acquisitions were repeated and/or the acquisitions were made for several phi angles in order to have higher diffracted intensities. It would be beneficial to check the reproducibility of the results in other regions of the samples, because residual stresses profiles were measured in one specific location only. For such reason we intend to submit another proposal for new stress measurements in the future.

Besides the experimental difficulties, the HT620 sample presented the highest residual stress relaxation in both weld regions when compared to the as welded sample. The corresponding heat treatment of sample HT620 has the industrial benefit to be shorter (only 1 hour) than the HT540 (10 hours).

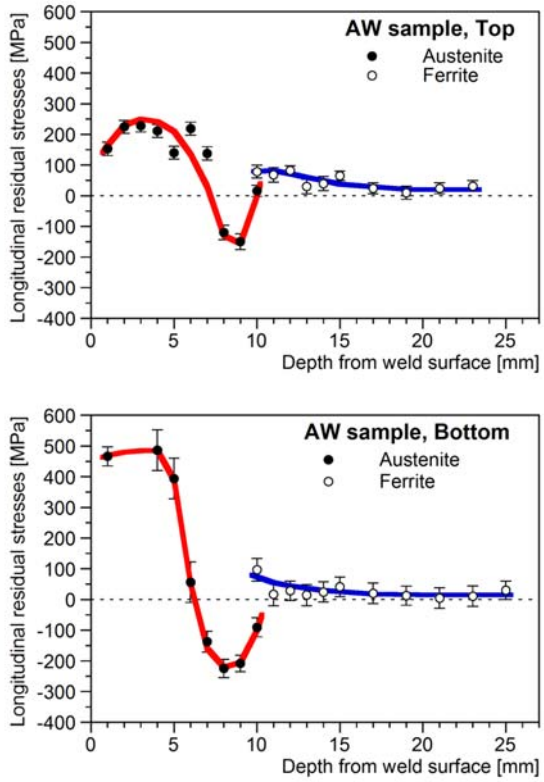


Fig. 3 - Residual stresses profile in longitudinal direction of the weld in the as-welded sample (AS):
a) in the central region (top) and
b) in the border of one weld pass (bottom) .

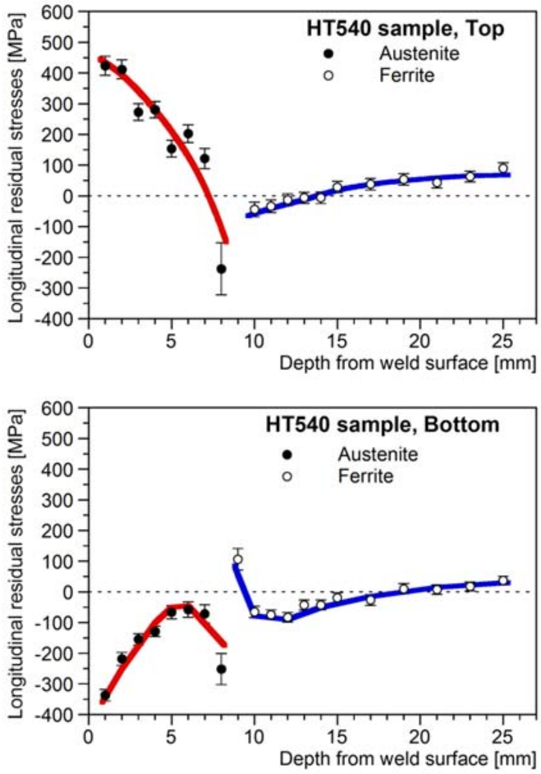


Fig. 4 - Residual stresses profile in longitudinal direction of the weld, in the sample HT540:
a)- in the central region (top) and
b)- in the border of one weld pass (bottom).

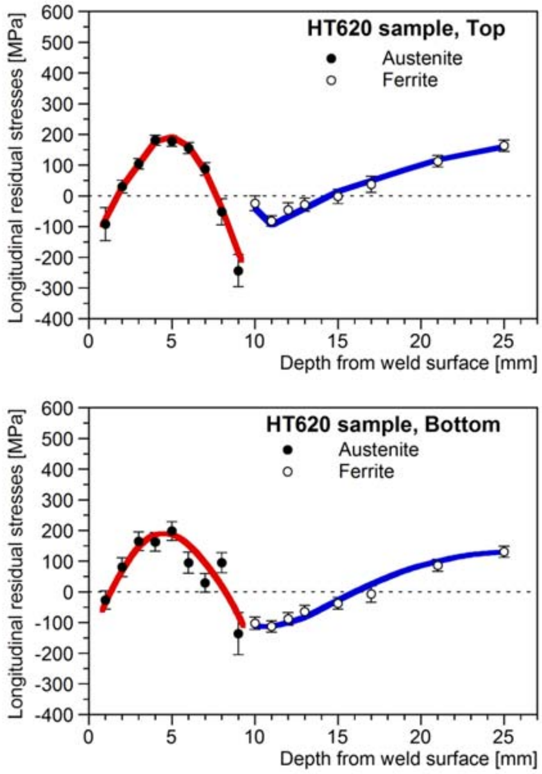


Fig. 5. Residual stresses profile in longitudinal direction of the weld, in sample HT620:
a)- in the central region (top) and
b)- in the border of one weld pass (bottom).

4- ACKNOWLEDGMENTS

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