Some Aspects Regarding the Fracture of Welding Joints Applied on Austenitic Steels and INCOLOY Alloys

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ABSTRACT. *Initial material structure, welding parameters as well as subsequent processing or loadings can drastically influence the durability of welded parts fabricated from austenitic steels or super-alloys. Metallographic analysis performed on a considerable number of TIG welded joints between parts fabricated from austenitic steels such as AISI 304, AISI 309, AISI 316 or INCOLOY 800 superalloy allowed identification of different fracture types caused by processing factors: inadequate geometry of the joint, flaws inside the joint or on the heat affected zone (HAZ). Another category of fracture causes is represented by the service conditions such as inter-crystalline corrosion or stress corrosion. The fracture mechanism has been analyzed also as in connection with the processing by mean of cold deformation that was applied after the welding. Some representative examples are presented by mean of metallographic analysis on samples that contained cracks or fractures produced during processing or in service. The analysis procedures, which were applied in different stages of the fabrication route, permitted the identification of specific causes that produced fracture or formation of cracks.*

INTRODUCTION

Austenitic stainless steels are the most used materials for the production of sheathed heating elements, especially for the exterior parts that are required for specific safety conditions.

In order to comply with these conditions some the steel has to satisfy several properties, the most relevant being behavior to welding and cold deformation, as well as a very good corrosion resistance inside the working environment [1].

If any of the above mentioned properties is not achieved cracks will occur and the heating element will go out of service as effect of sealing loss.

Accordingly to the processing and functioning conditions, the shielding tubes are produced using austenitic stainless steel of the AISI 300 class (16-25 % Cr and 8-20 % Ni), or INCOLOY 800 (18-23 % Cr and 30-35 % Ni), which although is not actually a steel grade, but more like a superalloy, has similar behavior as effect of its austenitic structure.

Investigations performed on a considerable number of samples prepared after different processing stages or after certain periods of service have evidenced some possible causes for defects that could produce loss of integrity, as effect of cracking or corrosion.

Special attention has been given to structural changes inside the material during fabrication of heating elements and possible effects upon further processing and service behavior.

INVESTIGATION OF WELDED JOINTS

Protection shields for heating elements are produced using cold laminated strips of steel (thickness (0.4-0.5 mm), deformed and subsequently TIG welded.

The structural appearance could be explained considering the solidification process. If rapid solidification occurs (thermal gradient $\frac{dT}{dx} = G_2$), elements diffusion is limited, which is producing a constitutional supercooling (liquid near the solidification front has a lower temperature than the equilibrium level) (Figure 1).

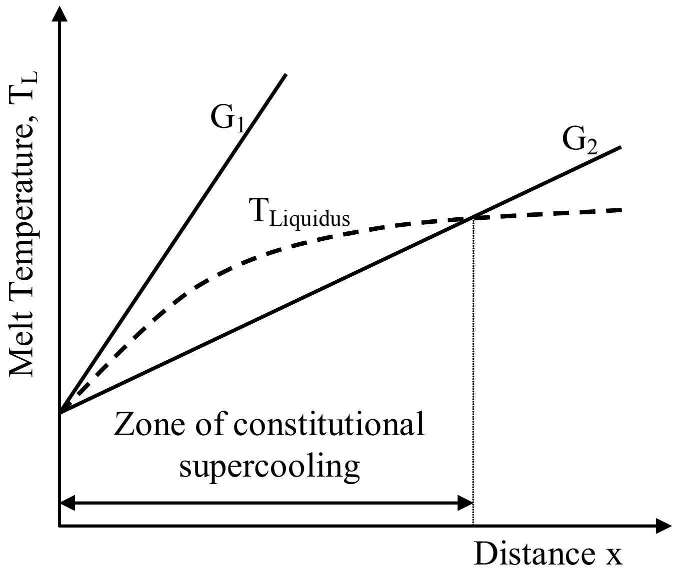


Figure 1. Characteristics of the zone of constitutional supercooling.

Therefore the solidification will not be plane anymore, and columnar or dendrite crystals will develop inside the melt. The degree of constitutional supercooling has inverse proportionality with the following ratio (Eq. 1):

$$\Delta T = \frac{D \cdot G}{\sqrt{R}} \qquad (1)$$

Where the following quantities represent respectively:

G - the temperature gradient,

R - the velocity of solidification front,

D - the diffusion factor of the solute inside the melt [2].

For large values of ΔT the grains which appear inside the melt have a cellular shape. Meanwhile for reduced of this ratio the crystals are dendrites [3].

The development of these formations starts from the crystals near the melting line, and will be accomplished parallel with the crystallographic direction most favorable for crystallization (direction ‹1 0 0› for the CFC system). For this reason, dendrites grown on grains where the ‹1 0 0› is perpendicular to the melting line will develop preferentially (Figure 2).

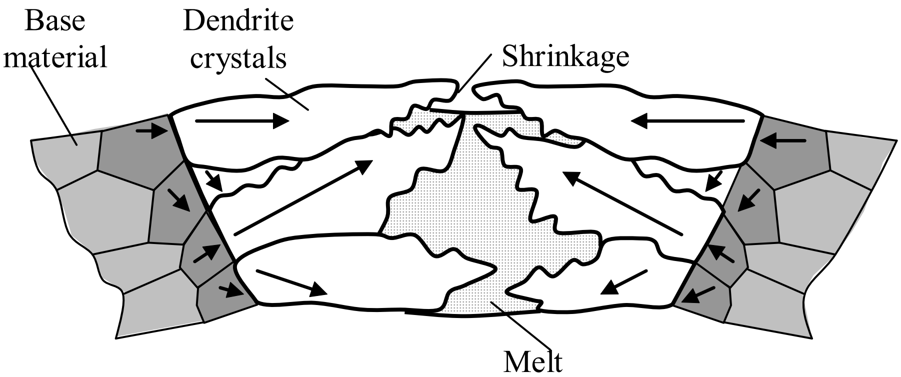
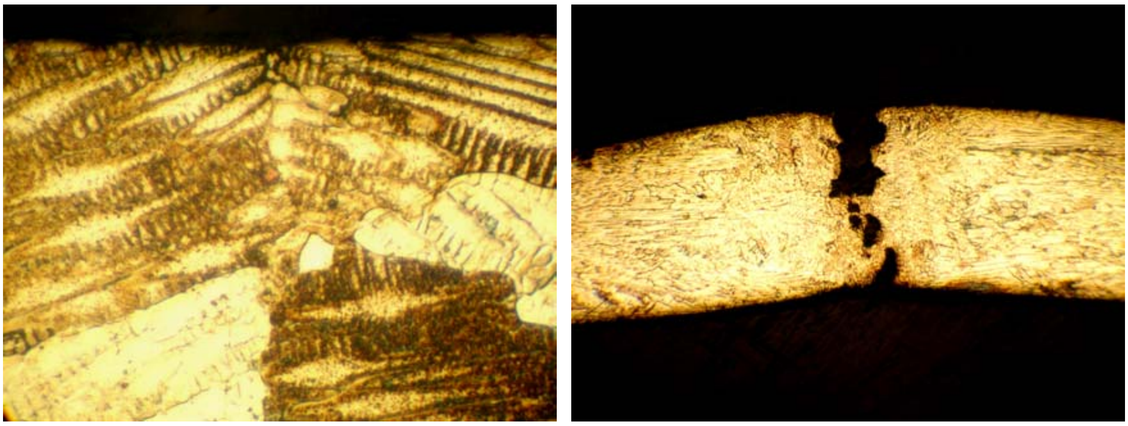


Figure 2. Mechanism for preferential development of crystals inside the melt.

The typical microstructural appearance of the welded joint is presented by Figure 3.

Figure 3. Characteristic appearance of a welded joint, with evidences of columnar grains inside the joint, optical magnification OM 50x.

The above presented solidification mechanism is favoring rejection of inclusions toward the joint axis, especially on its upper area. On the same time, within the superior area of the axis, there are some possibilities for the formation of micro-shrinkages (Figure 4 a).

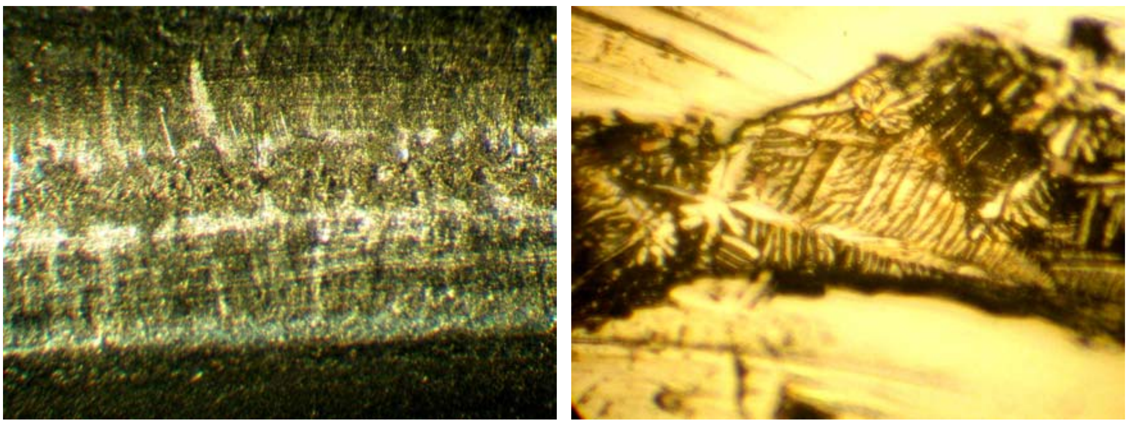


a) OM 500x b) OM 100x

Figure 4. a) Micro-shrinkage and inclusions within the joint axis area; b) Fracture at the joint axis.

The presence of a micro-shrinkage or of some inclusions within the central area of the joint axis (where the two solidification fronts meet) favors the formation of cracks at the tube joint (Figure 4 b).

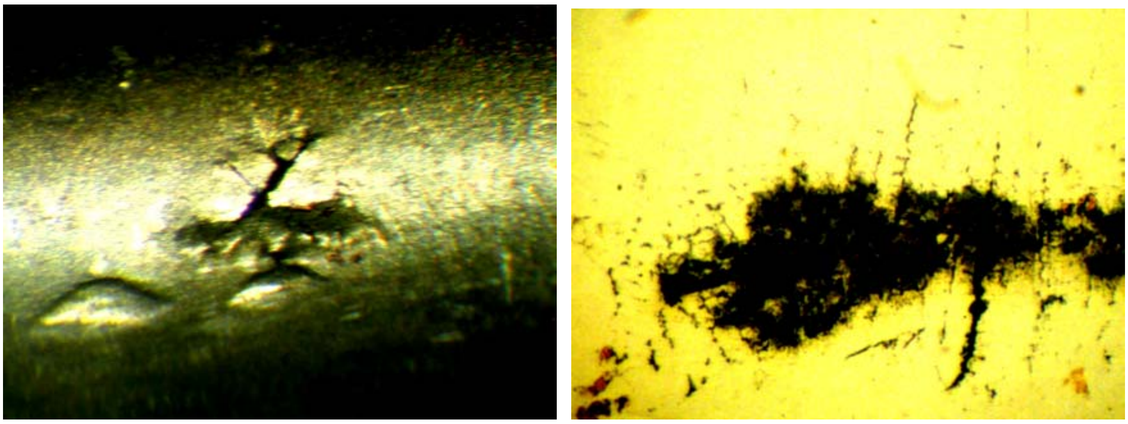
The crystalline dendrites, the micro-shrinkage and the non-metallic inclusions accumulated inside the central area of the welded joint have been evidenced by mean of macroscopic analysis (Figure 5 a), as well as by optical microscopy, using an unprocessed and unetched sample (Figure 5 b) [4,5].



a) OM 40x b) OM 500x

Figure 5. Free superficial dendrites on the tube exterior.

The presence of discontinuities as well as the agglomeration of inclusions inside the exterior area of joint axis is creating in this area a crack seed (Figure 6).



a) OM 40x b) OM 500x

Figure 6. a) Micro-shrinkage and agglomeration of inclusions within the exterior surface of the joint axis area; b) Cross section through the joint axis.

Metallographic processing of a section containing defects similar to those presented by Figure 6 a) evidenced the micro-shrinkage at the joint axis, the inter-dendrite spaces and some agglomerations of inclusions of the Ti (C, N) type (Figure 6 b).

One of the defects which appeared during the welded tube processing is represented by some transversal cracks in the proximity of the welded joint (Figure 7).

Figure 7. Transversal cracks initiated inside the welded area, within the tube bend.

In order to reveal the nature of these cracks an investigation based on multiple longitudinal sections at low depth has been executed within the joint area. The analyzed microstructures indicated cracks of different extensions, parallel to each other and perpendicular to the tube generator (Figure 8).

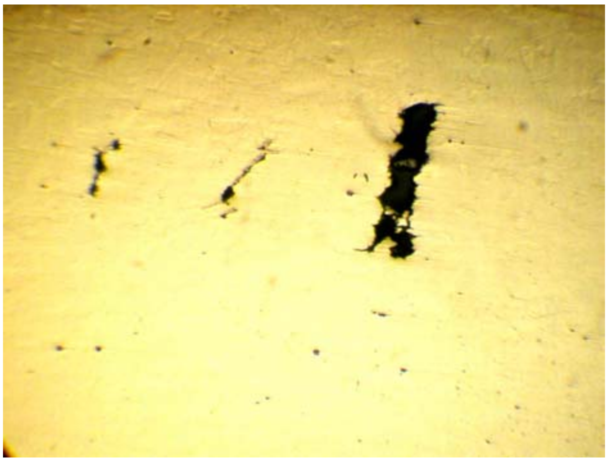


Figure 8. Transversal micro-cracks inside the joint, revealed on an unetched sample (OM 100x).

One microstructural detail produced by etching (Figure 9) evidenced a crack (on the left side) and inter-dendrite spaces that produced cracking seeds (on the right side).

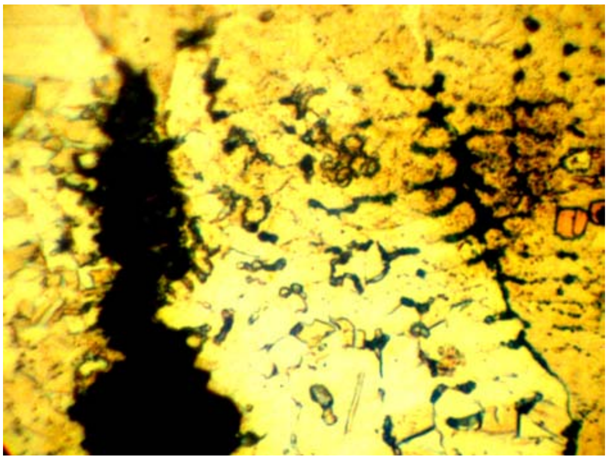
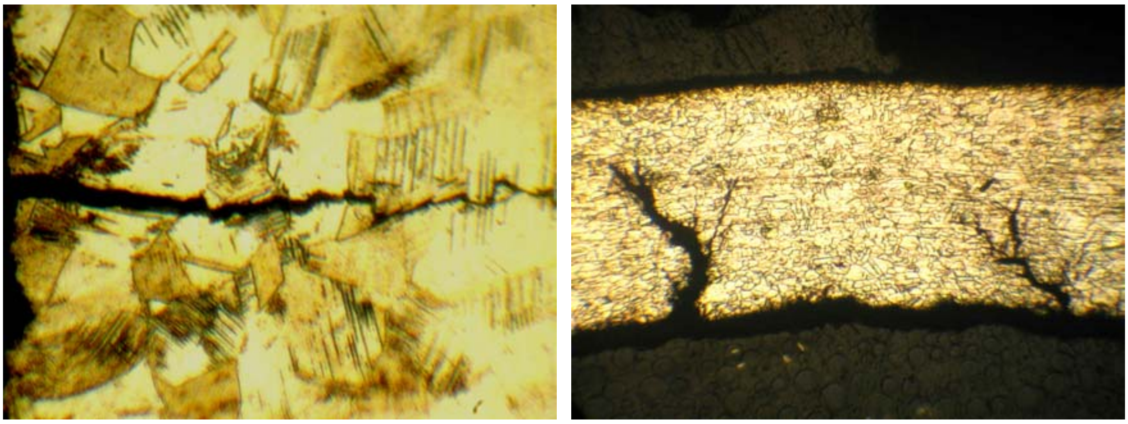


Figure 9. Area containing cracks and inter-dendrite spaces revealed on a longitudinal section, OM 500x.

The presence of some high level internal stresses inside the shield of the heating element may also contribute to acceleration of stress corrosion [6].

Figures 10 a) and 10 b) present the mechanism of inter-crystalline and intra-crystalline propagation of a crack within an area with high stresses, evidenced by the presence of material flowing lines inside adjacent grains. Development of these cracks during the service period is favored by the action of the working environment and may lead to penetration of the shield wall [7].



a) OM 500x b) OM 100x

Figure 10 a) Stress corrosion inside a deformed area; b) Cracks propagation as effect of stress corrosion.

The presence of inter-dendrite spaces and accumulation of inclusions at the limits of dendrite crystals is also obvious inside samples, which were annealed after welding and plastic deformation.

CONCLUSIONS

Welded joints on the protection shields of the heating elements must guarantee some technological and operational characteristics of the material.

Plastic deformation produced after welding, as well as subsequent heat treatments will add considerable stress inside the welded area, significantly increasing the risk for generation of cracks.

In order to satisfy the required characteristics there is an imperative necessity for the use of materials with appropriate behavior during welding and plastic deformation (AISI 300 class steels or INCOLOY 800 super-alloy) with high purity, since inclusions could produce major defects inside the welded joints.

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