Mater. Res. Soc. Symp. Proc. Vol. 1372 © 2012 Materials Research Society
DOI: 10.1557/opl.2012.122

Characterization of Metallurgical Defects in the Melt Zone of 304L Steel Tubes Manufactured by GTAW Process

J.J. Ruíz- Mondragón[1], J. Acevedo-Dávila[1], F. García-Vázquez[1] and H.M.Hdz-García[1]

[1]Corporación Mexicana de Investigación en Materiales (COMIMSA). Calle Ciencia y Tecnología No 790 Fraccionamiento Saltillo 400, Saltillo, Coahuila, México, C.P. 25290. E-mail: jjorge.ruiz@comimsa.com

ABSTRACT

This study consisted of the characterization of longitudinal cracking pattern observed in weld joint in the manufacture of 304L steel pipelines with thin wall thickness by GTAW process. These tubes are used in food and automotive industries. The cracks grown in the liquid-solid interdendritic zones at high temperatures. It was found that the cracks are associated with change on solidification mode and presence of the holes produced by shrinkage. The change in the solidification mode was associated with the presence of second phase particles. The results suggest that the formation of cracks is promoted by increasing current during the welding although the heat input is constant.

Keywords: welding, defects, second phases, stainless steel, scanning electron microscopy (SEM)

INTRODUCTION

The stainless steel pipelines of thin wall thickness are widely used in the food and automotive industries in the fabrication of the heat chambers or fluids transport because the good properties of the stainless[1,2].

Nowadays there are two methods for the production of 304L steel tubes, by extrusion process, cold-rolled and welding which is the most employed for the lowest cost of production. Due to that is necessary to perform a weld joint with high level of quality and considerable precision; in this sense the gas tungsten inert arc welding GTAW or TIG process is the best choice. The disadvantages of this process are the penetration which can be achieved in a simple pass and the low velocity production.

Some researchers suggest to increase the current during the welding process in order to increase penetration or to use the flux with the aim of increase the metal resistivity [2]. Several defects as holes, micro-holes, shrinkage, micro-shrinkage and cracks are found during the manufacture of 304L stainless steel tubes by GTAW process. The principal problem that shows the stainless steel weld is the high hot crack susceptibility [3]. Many researchers have reported [3-5] that the high level or cracking has relation with the ferrite content poor during the solidification process.

The present study has been conduced to found the relation between the welding process parameters and defects generated in the stainless steel pipelines joint by GTAW process and to suggest the suitable process parameters to avoid defects formation.

EXPERIMENTAL PROCEDURE

Stainless steel 304L plates of chemical composition in wt% (0.02C-1.74Mn-0.34Si-17.9Cr-7.9Ni-0.162Cu-0.118V) with 1 mm thickness were employed; the plates were cold-rolled and joined by GTAW process. Table I shows the welding parameters used in this research. The microstructural characterization of the welding zone samples was carried out by optical microscopy (OM) and scanning electron microscopy (SEM).

Table I. GTAW process parameters used in the stainless steel tubes production.

Sample	Voltage (V)	Current (A)	Welding velocity (mm/min)
1	14	170	180
2	14.3	173	155
3	14.8	176	160
4	14.9	174	180
5	15	162	158
6	15	162	158
7	16.1	164	160

Characterization of the weld joint

The surface cracks were found by visual inspection at the fusion zone. The typical defects were carefully extracted from the tube by cutting off small pieces that contained them, avoiding an excessive heating of areas very close to the cracks. Finally, the surfaces generated by propagation of the cracks were separate and analyzed using a scanning electron microscope (SEM).

With the aim of know about the effect of the weld parameters variation on the lineal defects as cracks, the fabrication of stainless steel tubes were made with different values of process parameters. The welding zone was evaluated with the purpose of found the relationship between the process parameters and the cracks located in the fusion zone of the joint.

RESULTS

Figure 1a shows the crack found in the surface of weld joint, its size is around of 5 mm length. The cracks did not grow in lineal pattern which suggest that it is propagate through grain boundaries. Figure 1b shows the photography of the weld joint in near the cracks; in this zone it is observed the patron of solidification with form of the diamond. It is growing the continuous form in a long of the weld join.

Figure 2 shows the image obtained by SEM in the weld joint surface where the crack is located. It is observed that the crack is nucleated in the vertices of the diamond zone and it was propagated around the diamond generated. The diamond geometry was produced by a change of the solidification pattern. The dendrites did not grow in epitaxial form which is observed commonly in weld joint, they start growing at the center of diamond in heat extraction direction.

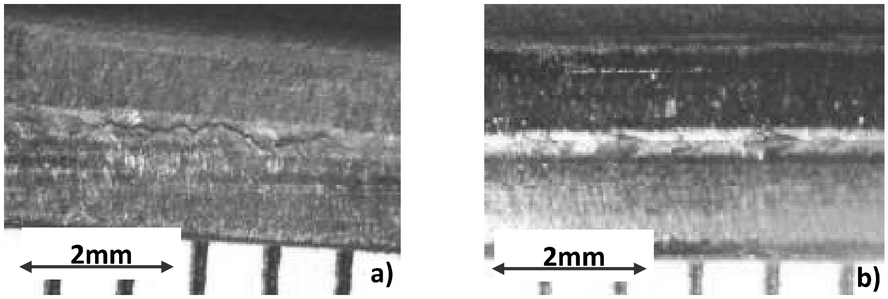

Figure1. a) Crack found in the surface weld join and b) Solidification with diamond pattern on the fusion zone near of the cracks.

Figure 3a shows the diamond central zone at high amplification, it shows the change in the solidification pattern generated by the particles of second phase, i.e. these particles acts as nucleation center. The particle was constituted by calcium, aluminum and oxygen in high proportions according, 8, 13 y 30 wt% respectively, to the energy dispersive spectrometry (EDS) spectrum shown in the Figure 3b.

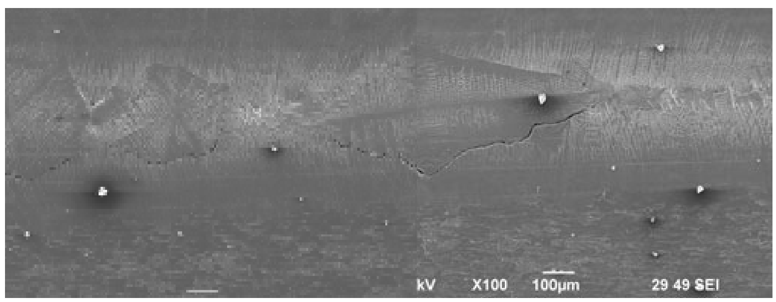

Figure 2. Secondary electron image of crack zone, observed at 100X.

Figure 4 shows a magnification of the interface between two diamond patterns, it is observed holes or cavities generated in the interface. This kind of defects promoted the formation of defects as cracks; the diamond patterns act as centers of strength concentration.

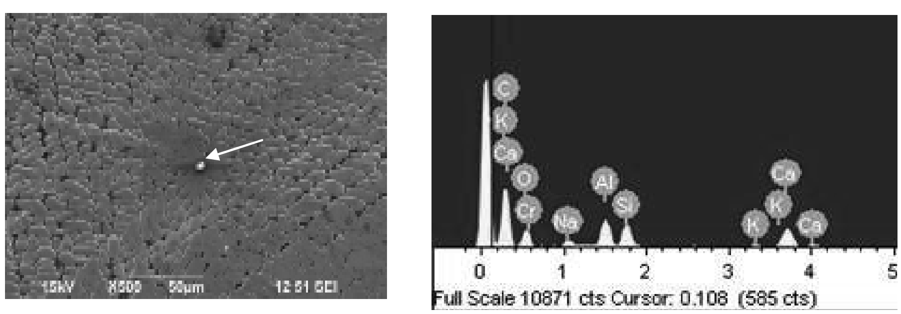

Figure 3. a) Micrograph obtained by SEM at diamond center zone, observed at 500X and b) EDS spectrum of latter particle central.

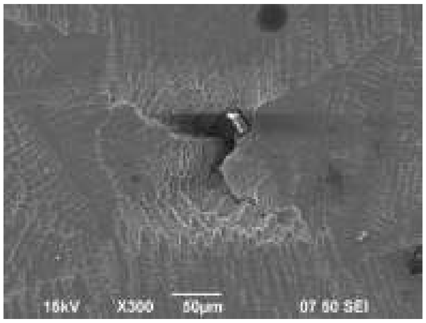

Figure 4. Secondary electron image of the interface between the two pattern diamonds obtained by SEM at 300X.

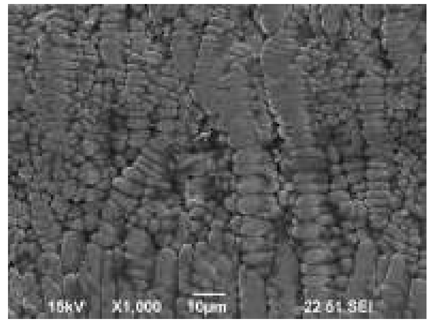

Figure 5. Micrographs of the weld zone free of defects obtained by SEM at 1000X.

Figure 5 shows the micrograph of the sample 7 of the weld joint zone obtained by SEM, as can be seen in this area was not present defects and diamond pattern microstructure. This image shows the epitaxial form growth of dendrites from base metal and does not show the change in the solidification pattern.

DISCUSSION

The chromium to nickel equivalent ratio (Cr_{eq}/Ni_{eq}) was calculated using the WRC-1992 equation. The value was estimated of 1.96, this suggest that the solidification mode is ferrite-austenite (FA). However, the mode of solidification shows the lowest index of hot cracking [4,6]. The inspection in the samples shown in the Figure 1, 2, suggest that in addition to the stresses generated by the solidification, the cracks can be promoted by the change of the solidification pattern generated for the precipitation of the second phases as oxides and carbides during the weld. The change in the pattern solidification promoted the increase of the crack susceptibility, however it is more remarkable if the precipitation of second phase particles is more continuous because they promote formation of micro shrinkage and holes.

When the zone near of the vertices of the diamond pattern solidify rapidly the liquid metal cannot compensate the shrinkage, therefore it causes the formation of holes, which increase the susceptibility crack, for the absence of metal. Jang *et* al. [6] they studied about the effects of weld microstructure and residual stress distribution on the fatigue crack growth rate of stainless steel narrow gap welds, found that two mechanism of crack to grain boundary sliding when it suffered from strong stress and the intersection or the triple point of the grain boundary carried a significant risk of crack generation [6-8]. The second mechanism was obtained in the microestructure that the holes in the triple points promoted the detrimental effects of the stress concentration on these zones.

Figure 6 shows the results for the visual inspection of the weld join obtained under several parameters as Voltage, V, Current, I, and Weld Velocity. These parameters were used to estimate the heat input, in function of the equation 1. The defects were function of the weld parameters. Although the heat input is constant, if the current arise 170A is promoted the formation of the particles of second phase which change the solidification pattern increasing the susceptibility of crack.

$$Heat\ input = \frac{Voltage \times Current}{Weld\ velocity} \qquad (1)$$

The mechanism of formation the second phase is function the heat input introduced in the system. The results suggested that the inclusions in the steel are melt during the weld process, these coalesce before solidification. The new particles solid work that nucleation centers for promoted the heterogeneous solidification. The heterogeneous solidification takes part in the increasing of crack susceptibility when the solidification forms the holes o microholes between the diamonds.

The formation of the cracks when the heat input is higher can be explained with the results found for Kummar and Shahi [9]. They found that the dendrite size in the fusion zone is smaller in low heat input joints than the dendrites in medium and high heat input joints, it is found that maximum tensile strength and ductility is possessed by the weld joints made using low heat input. For these reason with high heat input, increasing the possibility found cracks because the low ductility for the weld joint.

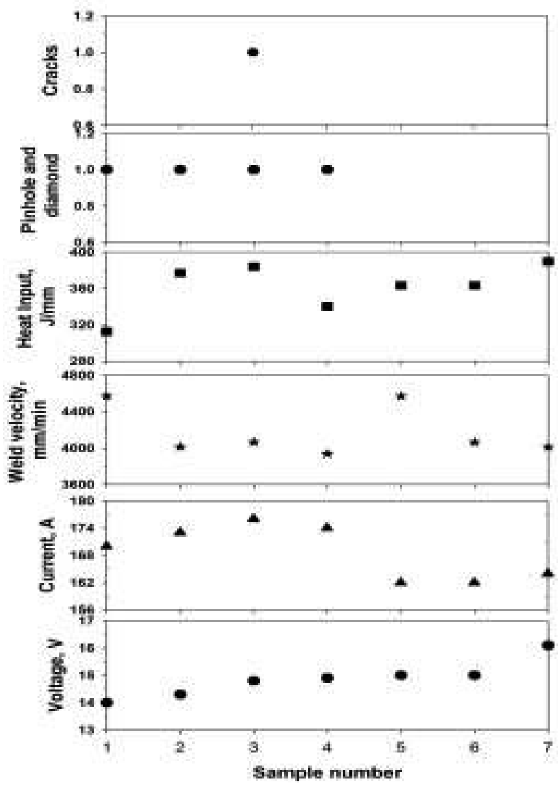

Figure 6. Relationship between the parameters of operation (I, V and Weld Velocity) and defects (shrinkage, diamonds and cracks) with the sample.

CONCLUSIONS

Characterizations of surface defects in the zone fusion of the weld joint allowed drawing the following conclusions:

1.-The change in the solidification pattern in the join of 304L stainless steels tubes made by GTAW process arise the susceptibility of the crack.
2.- The change in the solidification pattern is promoted by the precipitation of particles of second phase.
3.- The particles precipitation frequency of second phase arise when the current applied in the process is higher, promoting the formation of micro shrinkage o holes although the heat input are constant.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the technical supports of COMIMSA and Tubos Samuel de México S.A. de C.V.

REFERENCES

1. S. Kou. "Welding Metallurgy" (J. Willey 2003) p 457.

2. S. W. Shyu, H. Y. Huang, K. H. Tseng and C. P. Chou. J Mater. Engineering and Performance 17, 193-201 (2008).

3. Z. Li, H. Zhong, Q. Sun, Z. Xu and Q. Zhai. Materials Science and Engineering A 506, 191-195 (2009).

4. J. C. Lippold and D. J. Kotecki. “Welding Metallurgy and weldability of stainless steels”. (John Willey 2005) p357.

5. P. S. Korinko and S.H. Malene, *ASM International* **4**, 61-68 (2001).

6. A.Y. Jang, D.J. Lee, S.H. Lee, J.H. Shim, S.W. Kang, H.W. Lee, *Materials & Design* **32**, 371–376 (2011).

7. R. Kacar, O. Baylan . *Materials & Design* **25**, 317-329 (2004).

8. K.H. Lo, C.H. Shek, J.K.L. Lai. *Materials Science and Engineering: R: Reports* **65**, 39-104(2009).

9. S. Kumar, A.S. Shahi. *Materials & Design* **32**, 3617–3623 (2011).