Post Weld Heat Treatment Qualification of Type 304L Stainless Steel Weld Metal

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***Abstract*—The micro-structural changes in type 304L stainless steel post weld solution treated at 1060 °C for 15 minutes time were studied using streicher screening corrosion test, hardness traverses, repeated solution treatment cycles, delta ferrite measurements and optical microscopic techniques. The aim of the present paper is focused on post weld heat treatment qualification by describes the results of an investigation to understand the micro structural changes that taken place in type 304L stainless steel weld deposits as function of temperature / time by showing any presence of re-crystallization and / or strain induced grain boundary migration and the dissolution of any carbide formed at grain boundaries in welding monitored by metallographic examination.**

***Keywords*—** 304L Stainless Steel, Annealing Twins, Recrystallized Grains, Delta Ferrite, Streicher Corrosion Test.

1. INTRODUCTION

Austenitic Stainless Steels (ASS) are widely used in high performance pressure vessels, nuclear, chemical, process and medical industry due to their very good corrosion resistance and superior mechanical properties. The austenitic stainless steels are prone to sensitization when subjected to higher temperatures (673 K° to 1173 K°) during the manufacturing process (e.g. welding) and /or certain applications as example pressure vessels [1]. However the (ASS) type 304L is being extensively used in the field of defenses and nuclear applications due to its excellent corrosion resistance in seawater environment [2]. This property of 304L is due to the presence of molybdenum, which prevents chloride corrosion. It also has a low carbon content due to which the wear and friction properties are improved and a lower susceptibility to intergranular corrosion [3,4]. During sensitization, chromium in the matrix precipitates out as carbides and intermetallic compounds (sigma phase) decreasing the corrosion resistance and mechanical properties [5]. In the present investigation, 304L austenitic stainless steel was subjected to different heat inputs by plasma arc welding (PAW) and gas metal arc welding (GMAW) in three pases followed by post – welding solution treatment at 1060 °C for 15 min. Shielded metal arc welding process using a standard 308L electrode. The micro structural developments were characterized by using optical microscopy. It was observed that even at the highest heat input, shielded metal arc welding process does not result in significant precipitation of carbides or intermetallic phases. The ferrite content and grain size increased with increase in heat input. The grain size variation in the fusion zone/heat affected zone was not effectively captured by optical microscopy. The as-weld metal is normally characterized by a cast austenitic dendrites structure with very small of ferrite distributed at inter dendrites boundaries and arms depending on the welding method. However certain of residual stresses will be affected in the structure being maximum at the middle of the weld metal. On subsequent solution treatment aiming at the dissolution of any carbide formed at grain boundaries in welding, secondary process may take place in the weld metal. These are:

1) The dissolution of some residual delta δ - ferrite in the austenite denderites.

2) The start of re-crystallization processes and/or strain induced grain boundary migration.

However the extent of the previous processes will depends on the treatment time and temperature as well as the level of residual stresses effected during welding. The dissolution of the δ - ferrite can not be taken as a criterion of solution treatment since it has only relative effect. The re-crystallization and / or strain induced grain boundary migration are irreversible processes and can be easily monitored by metallographic examination. The aim of the present study is to clarify experimentally the method has been used to trace the solution treatment that taken place in type 304L stainless steel weld deposits. The stainless steels type 304L is preferred over 300 series stainless steel as a major structural material in various high temperature applications due to its superior mechanical properties at elevated temperatures [4]. Data on the behavior of wrought 304 and 304L stainless steels are more extensive [6] than those concerning the weld metal. In order to reduce the crack susceptibility, the chemistry of the weld metal is suitably altered to provide some delta ferrite, normally between 2 and 10% [1]. However, the presence of delta ferrite is detrimental under certain conditions; (1) an enhanced attack of the weldments as seen in certain corrosive media [7], and (2) embitterment results from the precipitation of sigma at high temperatures[8,9]. Though such general trends in the behaviour of the weld metal are recognized, very little quantitative information is available on the kinetics of decomposition of delta-ferrite or the growth of secondary phases and their effect on the mechanical properties of the weld metal. The present paper describes the results of an investigation to understand the micro structural changes that take place in type 304L stainless steel weld deposits as a function of temperature and time. An important feature was the use of an electrochemical technique for the extraction and quantitative estimation of the secondary phases present in the weld metal.

2. DETAILES OF SPECIMENS

Two specimens (150 × 200 mm) from welded 304L stainless steel pipe of outer diameter 457.2 mm and thickness 14.7 mm welded by plasma arc (PAW) and gas metal arc (GMAW) in three passes followed (as claimed) by post welding solution treatment at 1060 ^oC for 15 min. Diameters and thicknesses have been claimed to be post welding heat treated by the producers and the goal of our studies were requested to check whether the treatment has been actually performed. The samples were prepared using standard metallographic techniques and etched in 10 ml HNO3, 10 ml acetic acid, 15ml HCL, and 2 drops glycerol for their observation on optical microscopy.

3. EXPERIMENTAL WORK

The specimens from welded 304L stainless steel pipe of outer diameter 457.2 mm and thickness 14.7 mm have been studied. The chemical compositions of these welded 304L stainless steel pipe are given in Table 1.

Table 1. The chemical composition of the material

Element	***Base***	***Weld***
C	0.019	0.025
Si	0.46	0.44
Mn	0.88	1.31
P	0.027	0.027
S	0.008	0.009
Ni	9.20	9.62
Cr	18.24	18.87
Mo	0.14	0.10
Fe	bal.	bal.

However the following experimental and tests have been performed :-

1- Streicher screening corrosion test for purpose to characterize the base metal with respect to inter-granular corrosion resistance [10] both in the as-received and after sensitization annealing.

2- Hardness traverses across the base metal, the heat affected zone (HAZ) and the weld metal to reveal any appreciable hardening in the HAZ which may be attributed to sensitizing.

3- Micro structural investigation of the weldment on cross sections to monitor any recrystallization or interdenderitic boundary migration events.

4- Repeated solution treatment cycles to check the time factor for the post welding heat treatment, followed by micro structural and micro hardness measurements to reveal the effect.

4. RESULTS AND DISCUSSION

The chemical composition of the pipe base and weld metals is introduced in Table1. However the results of the present study, obtained from the various techniques, are classified as:-

4.1 Streicher Corrosion Test

The microstructure of the as-received base metal obtained after streicher screening corrosion test (electro etching in 10% oxalic acid) is introduced in Fig.1. below

showing no signs of carbide precipitation at high angle grain boundaries could be observed indicating no sensitization. However Fig.2 introduces the microstructure of the same specimen but subjected to sensitizing annealing at 650^o C for 60 min. Some isolated precipitates are observed at high angle boundaries. Such type of dual microstructure is acceptable for 304L stainless steel. The average grain size generated of the base metal was determined using a linear intercept technique is found to be 20μm.

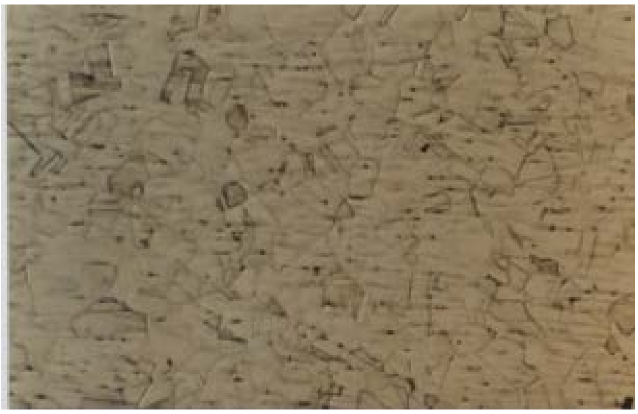

Fig. 1 Microstructure of the base metal as-received after streicher testing – 200X.

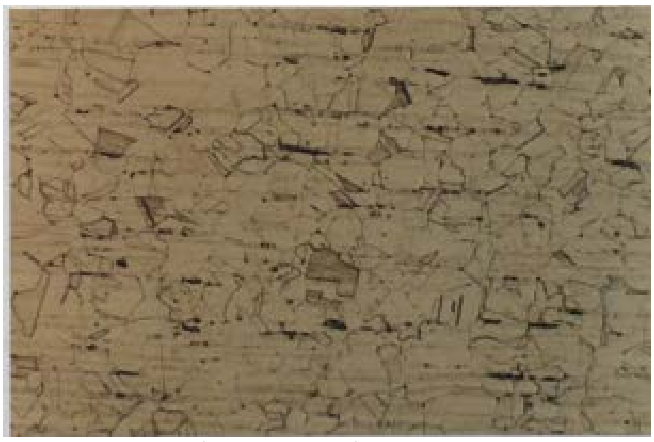

Fig. 2 Microstructure of the base metal after sensitization annealing and streicher test – 200X.

4.2 The Microhardness Test

For each specimen, the Vickers hardnes was measured using a 1 Kg/mm^2 as indentation load. The hardness measurement was carried-out at five points in the region of specimen where microstructure observation was made. However after the microhardness test, the hardness traverse across the weldment (Fig.3) didn't show any systematic hardening effect in the HAZ indicating no sensitization effects.

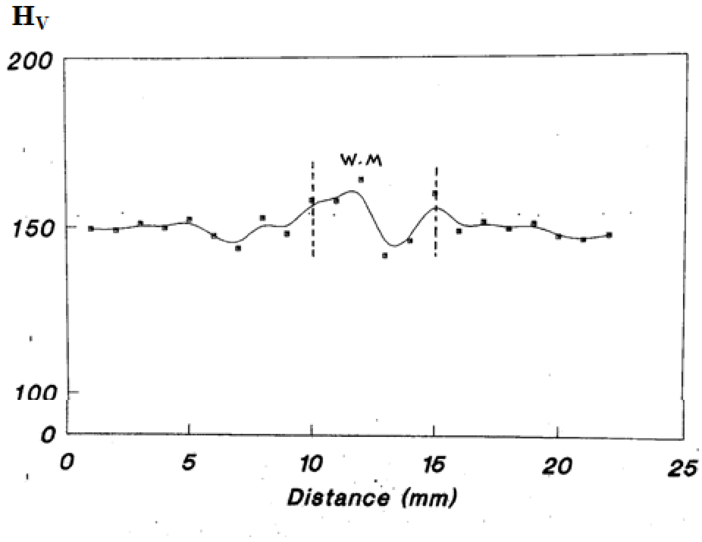

Fig. 3. Showing the hardness traverse the weld bead.

4.3 Micro Structural Investigation

The microstructure of the weld metal (Fig.4) indicates several recrystalized small grains with characteristic annealing twin boundaries as marked (a) on the figure 4. Occasionally same interdenderitic boundaries show signs of stress induced migration as marked (b) on the same figure. It can be concluded that the recrystallization processes have started in the weld metal of the as-received welded material.

4.4 Delta Ferrite Measurement

The δ- ferrite of the as-received material was evaluated by the point counting methods as 4 % which is acceptable for 304L type stainless steel.

4.5 Repeated Solution Treatment

Representative specimen were given additional solution treatment under the same regime as the claimed one. So the microstructure of the weld metal after repeated solution treatment (Fig. 5) revealed largely recrystallized structure, where small islands of the cast structure was retained. The average grain size of the material was observed to increase substantially during the treatment. Hardness traverser, however, did not show noticeable change. The δ-ferrie content of the weld metal decreased to 2.9 %.

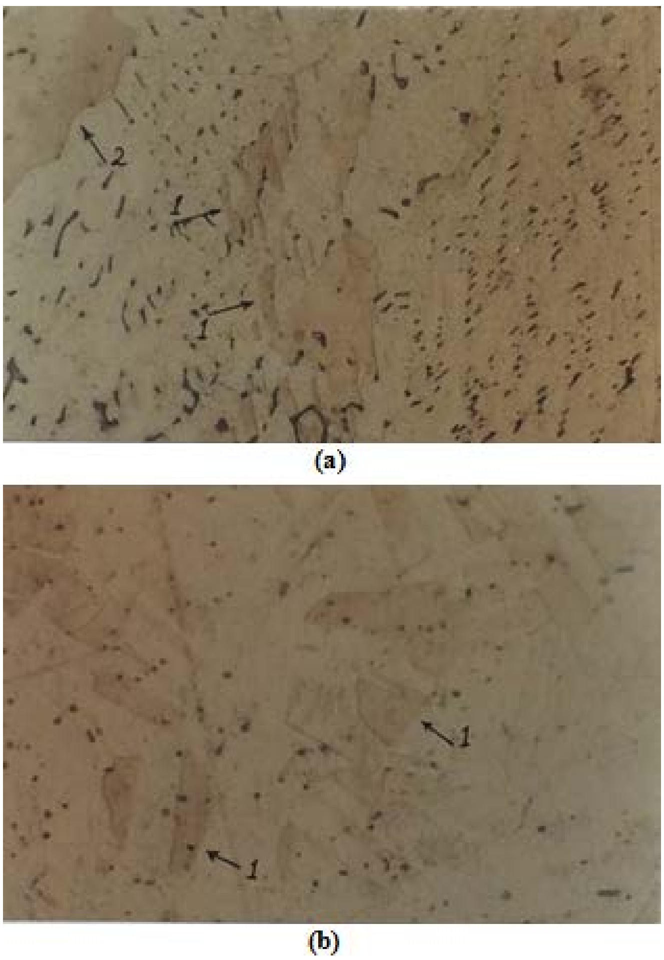

Fig. 4 (a , b) Microstructure of the base weld metal as received in two different positions (etched in 10ml HNO_3, 10 ml acetic acid, 15ml HCL, and 2 drops glycerol) – 400X

5. Conclusions

Taking into account the start of the recrystallization events in the as received material we can conclude that solution treatment has been performed for this welded pipe. Because of the other adverse effects observed after repeated solution treatment (e.g grain growth and decrease in δ-ferrie content). As final we can concluded that the pipe seems to have undergone solution treatment after the welding process and the time for solution treatment was properly selected and the are expected to show good intergranular corrosion resistance in service.

(a)

(b)

(c)

Fig. 5 (a , b and c) Microstructure of the weld metal after repeated solution treatment in three different positions (etched in 10ml HNO_3, 10 ml acetic acid, 15ml HCL, and 2 drops glycerol) – 400X

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