Fandem, J Material Sci Eng 2017, 6:2
DOI: 10.4172/2169-0022.1000329

Journal of Material Sciences & Engineering

Research Article Open Access

Deterioration of Stainless Steel Corrosion Resistance Due to Welding

Fandem QA*

Aramco Qatif, Eastern Region, Saudi Arabia

Abstract

The objective of this paper is to provide an overview of the main welding defects that frequently exist in piping and equipment and how to detect these defects without destroying the welds using Non Destructive Testing (NDT) methods. Then, the sensitization of stainless steel weld, characterization, processing and structure properties of HAZ as well as weld metal will be discussed in details. Furthermore, this paper will illustrate the treatment of the weld decay by recovery of passivation film after welding which will be followed by prevention of intergranular corrosion or weld decay of SS using surface mechanical attrition treatment and all of these will be described with help of characterization techniques XRD, SEM, TEM and EPMA.

Keywords: Welding; Welding decay; Stainless steel; Passivation; Sensitization; NDT; SMAT; Cr depletion

Introduction

Welding is an important technique of joining metals homogenously in industries due to its effectiveness with low overall cost. However, presence of welding imperfections is a challenge which may form due to poor workmanship such as cracks, porosity, lack of fusion, incomplete penetration and weld decay in stainless steel because of material properties issue. Furthermore, stainless steel material is one of the best choices in industries because of its high resistant to corrosion, however the issue with stainless steel material is the sensitization or weld decay after welding fabrication particularly in Heat Affected Zone (HAZ) [1-3].

Non-destructive testing (NDT) techniques

In order to check the soundness of the weld for the equipment without damaging or destroying it, the manufacturers or fabricators are using NDT methods. There are several types of these such as Penetrant Testing, Radiographic Testing (RT), Ultrasonic Testing (UT), Magnetic Testing (MT) and of course Visual Testing (VT). There are also advanced NDT techniques used for welding critical services such as Time of Flight Diffraction Ultrasonic (TOFD). Some of these methods will be discussed briefly in this report.

Penetrant Testing is simple and low cost technique used to detect open to surface defects such as crack by using three different sprayers i.e. penetrant, developer and cleaner sprayers. The applying procedure of this method is by cleaning the surface and applies the penetrant which is in red color, and then after five minutes the area cleaned off with use of the cleaner followed by applying the developer which is in white color to bleed out the penetrant and make a color contrast. The crack will be visible easily after application as in Figure 1. The disadvantages of this method are; used only for open to surface defects, temperature limit of 125 F maximum, cannot be used to measure flaw size [4,5].

Another NDT method is Ultrasonic Testing which is a manual and effective to measure the defect size as well as detect internal defects in the weld by sending a beam of sound waves with frequency range (>20,000 cycles per second). If there is any defect the waves will be reflected back to the probe and amplitude intensity displayed on the screen. The disadvantages are requiring certified operator, even with the certified personnel it is difficult to recognize the type of welding defect and no permanent record of the measured defects [6,7].

Radiographic Testing is one of the most effective techniques used to detect internal defects by sending X-rays from radioactive source (Ir 192 or Cobalt 60) placed at one side of the weld and on the other side an image film is placed with image quality indicator (IQI). The main disadvantages of this method are health hazardous, high cost and very sensitive to the defect orientation for example if there is a crack parallel to the X-rays as shown in Figure 2, it appears on the film as a dot and the interpreter will recognize it as porosity instead of the crack, that is why it is not recommended to use RT for crack detection or to be used at several different shooting angles at the same joints which means more cost [8].

Stainless steel's corrosion resistance deterioration due to welding

Stainless steel gains the property of corrosion resistant at room temperature from presence of Chromium Cr (at least 10.5%) and Ni elements. The Cr produces a passivation film layer (Chromium Oxide) over the surface when exposed to atmosphere which protects the

Figure 1: Crack is visible after applying the three sprayers.

***Corresponding author:** Fandem QA, Aramco Qatif, Eastern Region, Saudi Arabia, Tel: 966506859895; E-mail: q_2010@hotmail.com

Received March 20, 2017; **Accepted** March 27, 2017; **Published** April 07, 2017

Citation: Fandem QA (2017) Deterioration of Stainless Steel Corrosion Resistance Due to Welding. J Material Sci Eng 6: 329. doi: 10.4172/2169-0022.1000329

metal from corrosion. There are several type of SS based on formation temperature and Cr% i.e. Austenite has Face Centered Cubic structure (300 and 200 series), Ferrite has Body Centered Cubic structure (400 series**,** Martensitic has Body Centered Cubic structure... etc. [9].

Although the SS is highly corrosion resistant at room temperature, when it is exposed to high temperature such as welding process (500-800°C), the HAZ is susceptible to corrosion as intergranualr corrosion and Stress Corrosion Cracking (SSC) as shown in Figure 3. This is occurred due to chromium carbide precipitation at grain boundary which leads to chromium depletion, this is called sensitization [10].

Material and Methods

To understand the cause and characterization of the stainless steel corrosion as well as SCC, detailed experiments and results will be discussed for a material of ferritic SS 0Cr18Mo2Ti per [11]. The Manufacturing process sequence of 0Cr18Mo2Ti is vacuum melting technique (VMT), continues casting, plate mill, annealing and finally pickling. Moreover, the chemical composition and mechanical properties of the base metal material are listed in Table 1 [11].

A test plate of 0Cr18Mo2Ti with thickness 3 mm produced by VMT technique and heated for 10 min at temperature 850°C and then cooled by air. The plate was welded using SMAW process with lime titania super low carbon SS electrode. The chemical compositions of the weld in Wt.% are listed in Table 2.

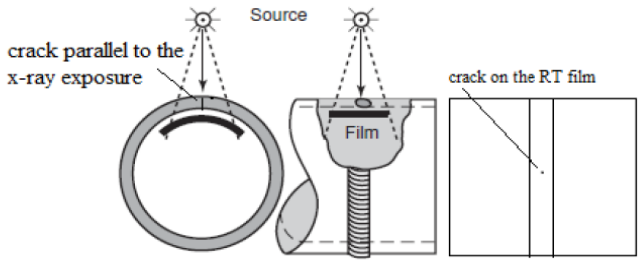

Figure 2: Sensitivity of RT to the crack orientation, the crack appears as porosity on the film [4].

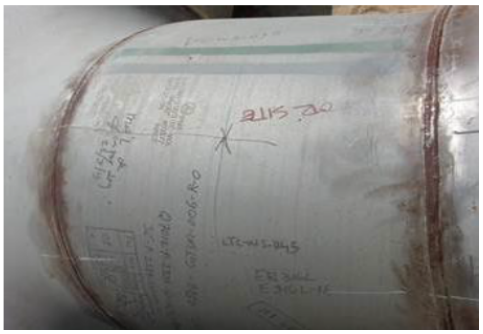

Figure 3: SS pipes welds got rusted after welding.

Also, the welding essential variables used as per welding procedure from ASME IX are listed in Table 3. The test specimens were prepared by cutting the weld from the weld and then an etchant (HNO_3 and HCl ratio 1:3) was used to display microstructures of the cut weld. The HAZ was analyzed by TEM and electron diffraction to identify the lattice structure as well as the microstructure. Moreover, the phase composition precipitation was identified by SEM, XRD and electron probe microanalysis (EPMA) [12].

Results and Discussion

The microstructures in the weld zone are austenite, ferrite and just a little of martensite, its morphology using SEM is shown in Figure 4a and 4b. Moreover, the weld was also analyzed by use of XRD with the following working parameters; voltage 40 KV, current 150 mA and scanning range 30-90 degrees. The result revealed that it is mainly austenite and ferrite just like in SEM.

For coarse grained heat affected zone (CGHAZ) which is only ferrite (single phase) and has al lower toughness due to heating up at high temperature during welding. Obviously, as we go far from the fusion line to the base metal, the grain size is reduced. Therefore, the welding heat input should be small enough as possible to prevent the microstructure coarse grain and hence the toughness reduction by following the proper welding procedure per ASME IX [11].

In order to get more detail analysis of the CGHAZ and the fusion line between the base metal-weld, thin films from these two zones were analyzed by TEM and electron diffraction. The TEM, electron diffraction pattern and indexing diagram of both zones were performed on [210] and [012] directions as shown in Figure 5 for CGHAZ and Figure 6 for fusion line.

It can be observed from the TEM Figures 5 and 6a, there are many dislocations and twin clusters exist inside grains due to the residual stress caused by welding. The diffraction pattern confirmed that the CGHAZ is a single phase ferrite with BCC structure and the lattice parameter a =0.2866 nm. Also for the fusion line, it is a single phase ferrite with a BCC structure. Furthermore, micro cracks were also observed at CGHAZ, this is due to the residual stress which is shown in Figure 7 [11].

Passivation treatment of stainless steel after welding

As mentioned previously the CGHAZ of stainless steel got affected after welding and the solution to recover the protection film is by performing passivation process. Passivation is the removal of impurities or iron from the surface and can be achieved by electropolishing, electrochemical cleaning or chemical passivation [12].

Electrochemical cleaning approach will be discussed in the report on 316L weld material. The surface was first polished with 1000 grit abrasive paper in Al_2O_3 (0.5 um) solution Figure 8. Then it has been cleaned chemically with 2% citric acid solution and 5% ammonia at 80°C. After that, the passivation was performed at temperature of 60°C with 6% HNO_3 solution that has $CuSO_4.5H_2O$ at 2%. The analysis of the surface was performed before and after polishing as well as after

Chemical Composition (wt%)									
C	**N**	**Mn**	**Si**	**Cr**	**Ni**	**Mo**	**Ti**	**S**	**P**
0.019	0.014	0.28	0.16	18.65	0.14	1.6	0.24	0.005	0.024
Mechanical properties									
Tensile Strength (Mpa)		Yield Strength (Mpa)			Elongation (%)		Impact energy (J)		
550-700 (560)		300-400 (360)			30-40 (34)		148-155 (152)		

Table 1: base metal's mechanical properties and chemical compositions [11].

C	Cr	Ni	Mo
<0.03	17-20	Nov-14	1.5-2.5

Table 2: Chemical composition of the used weld deposit [11].

Electrode Diameter (mm)	Welding Voltage (Volts)	Welding current (Amp)	Travel Speed (mm/s)
3.2	24-26	90-105	06-Aug

Table 3: Welding essential variables used for the plate [11].

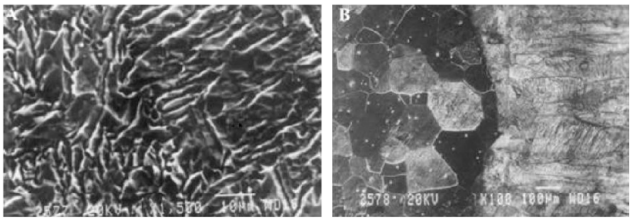

Figure 4: (a) Microstructures of weld metal SEM (X 1500), (b) weld metal & HAZ SEM(X100) [11].

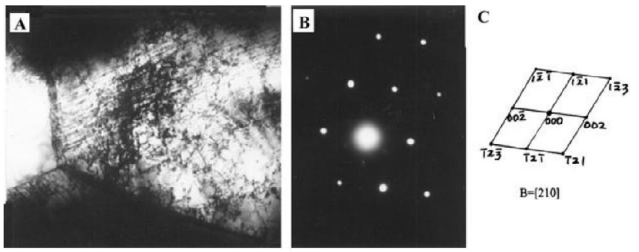

Figure 5: Structure characterization of CGHAZ (a) TEM morphology (X35000), (b) Electron Diffraction Pattern, (c) Schematic Diagram [11].

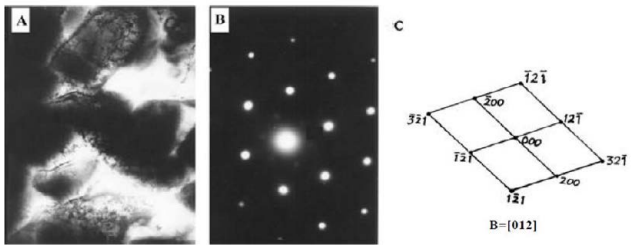

Figure 6: Structure characterization of welding fusion line (a) TEM morphology (X35000), (b) Electron Diffraction Pattern, (c) Schematic Diagram [11].

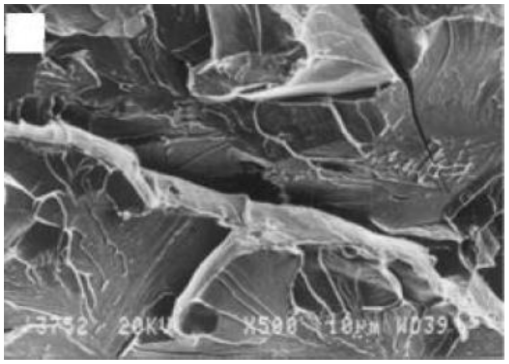

Figure 7: Micro crack in CGHAZ -SEM (X 500) [11].

passivation process. Figure 9 shows the SEM surfaces of base metal A and weld metal B, presence of cracks, grain boundaries and impurities are clear in both. On the other hand, the polished surfaces were characterized by smooth and uniform structure and the cracks as well as impurities were removed as shown in Figure 10.

After passivation SEM the base and weld metal were analyzed which presents an irregular distribution of indentations with a maximum diameter 5 um in the base metal as shown in Figure 11. Moreover, the quantitative analysis of the base metal has been performed by EDXS before and after passivation process as shown in Figure 12a and 2b. From this figure it is very clear that chromium carbide percentage dropped after passivation which enhances formation of the passivation film [12].

Prevention of SS corrosion using surface mechanical attrition treatment

The weld decay or the corrosion of SS material after getting exposed to high temperature such as welding process can be prevented by Surface Mechanical Attrition Treatment (SMAT) technique as per [10] in order to induce grain refinement as well as formation of twins.

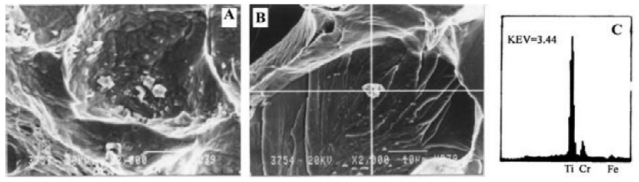

Figure 8: (a) Precipitates in CGHAZ SEM (X 2000), (b) Analysis location point for EPMA (X 2000), (c) EPMA spectra [11].

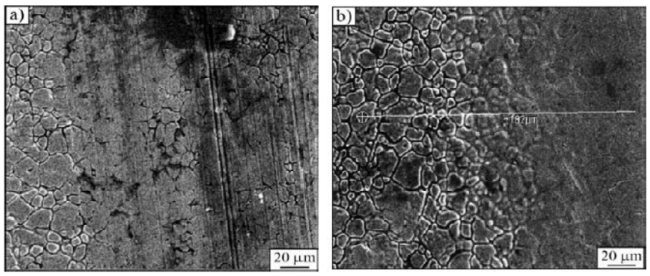

Figure 9: A (SEM) surface of base metal before polishing. B. Surface of weld before polishing [12].

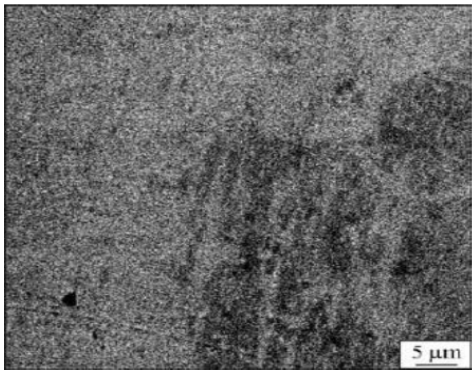

Figure 10: (SEM) the surface after polishing [12].

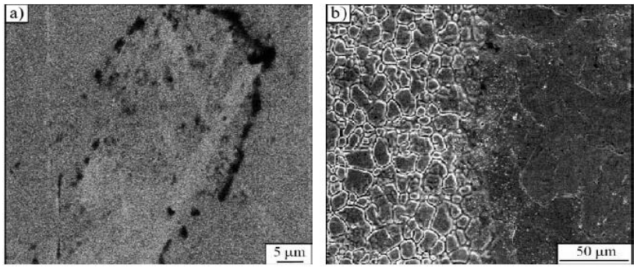

Figure 11: (a) (SEM) surface of base metal after passivation, (b) surface of weld after passivation [12].

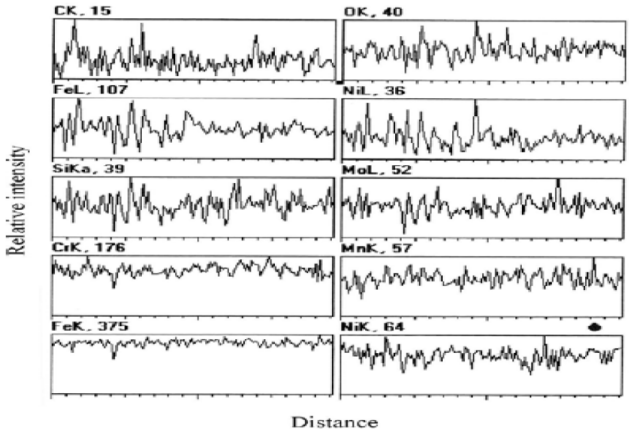

Figure 12a: (EDXS) Quantitative linear analysis before passivation [12].

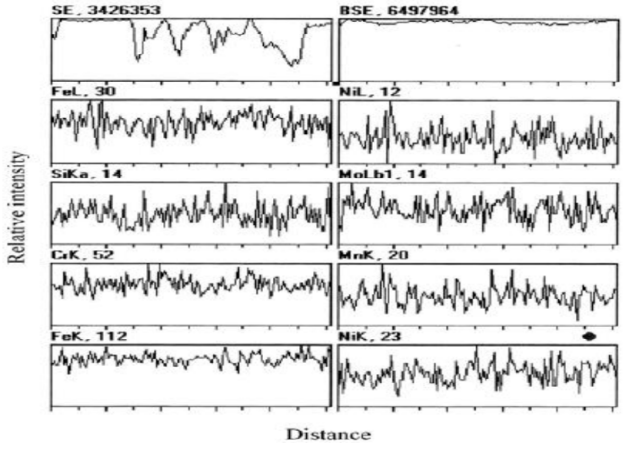

Figure 12b: (EDXS) Quantitative linear analysis after passivation [12].

SS 304 material has been used in this experiment with use of GTAW welding process. The samples were annealed at 1070°C for one hour and then quenched in water. The inducement of grain was refinement, the samples were put under vacuum at room temperature for 30 minutes with a vibrating frequency 20 kHz.

Optical micrograph of electroetching in 10% oxalic acid solution samples is shown in Figure 13. Grooved grain of the untreated sample are very clear, while for the SMATed ones are not. The single twins and their intersections can be seen with about 300 um thick below the surface. Moreover , TEM with magnification of 100 nm taken for the SMATed top surfaces as shown in Figure 14, which characterized by ultrafine equiaxed grains with random crystallographic orientation and as can be seen the average grain size is about 10 nm.

Moreover, SEM micrographs were also taken for the samples before and after SAMT as shown in Figure 15 and it is clearly observed the deep groove along the boundaries due to weld decay or the sensitization as Figure 15a and 15b. On the other hand, after treatment

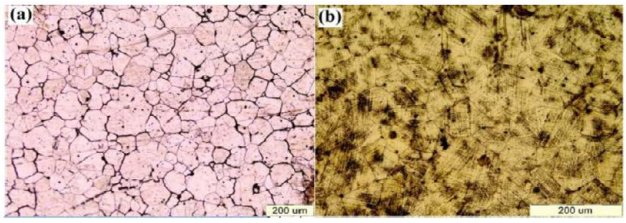

Figure 13: (a) Optical photos of untreated HAZ, (b) SMATed HAZ after electroetching [10].

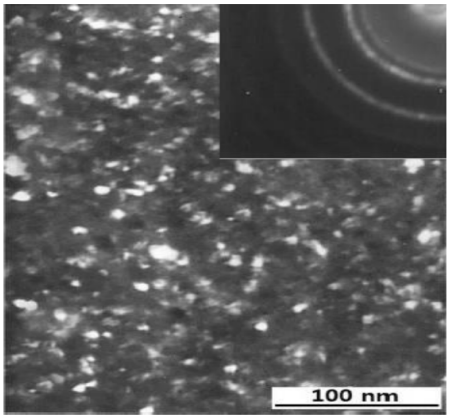

Figure 14: Dark field TEM of the top surface SMATed HAZ.

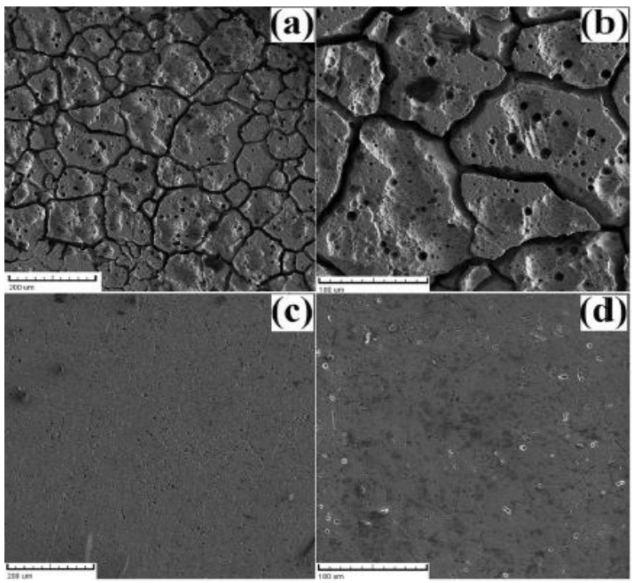

Figure 15: (a and b) SEM photos for untreated surface while, (c and d) for SAMTed surfaces [10].

the deep grooves in the boundaries become shallow and there is no sign for intergranular corrosion or sensitization because of formation high density twins as well as grain refinement. Thus, the SMAT improve the SS material to overcome the sensitization after welding by about 50 times than the untreated one [10].

Conclusions

It has been observed that the stainless steel material is corroded (weld decay) after welding due to sensitization or Cr depletion in the grain boundaries in form of chromium carbide. Thus, to enhance the recovery of the protection film, passivation treatment is used to clean the impurities or iron from the surface and hence the iron is reduced with recovery of Cr% atomic mass. Furthermore, the prevention technique with use of Surface Mechanical Attrition Treatment (SMAT) can be utilized before welding to enhance the sensitization for about 50 times. Also, it has been explained for the importance of the characterization techniques in failure investigation over the NDT methods with the example of SS welding.

References

1. Hayes B (1996) Classic brittle failures in large welded structures. Engineering Failure Analysis 3: 115-127.
2. Zerbst U, Ainsworth RA, Beier HT, Pisarski H, Zhang ZL, et al. (2014) Review on fracture and crack propagation in weldments-A fracture mechanics perspective. Engineering fracture mechanics 132: 200-276.
3. http://www.twi-global.com/technical-knowledge
4. API Standard (2004) Welding Inspection and Metallurgy API 577. American Petroleum Institute Washington.
5. ASME Standard (2007) Nondestructive Examination ASME V. The American Society of Mechanical Engineering. New York.
6. http://met-tech.com/crane-weldment-failure.htm
7. ISO 5817 (2003) Arc welded joints in steel-Guidance on quality levels for imperfections. Geneva: International Organization for Standardization.
8. Harrison JD (1972) Basis for a Proposed Acceptance-standard for Weld defects, Part. 1: Porosity. Metal Constr Br Weld J 4: 99-107.
9. https://en.wikipedia.org/wiki/Stainless_steel
10. Laleh M, Kargar F, Rouhaghdam AS (2012) Prevention of weld-decay in austenitic stainless steel by using surface mechanical attrition treatment. International Nano Letters 2: 37.
11. Yajiang LI, Yonglan Z, Bin S, Juan W (2002) Tem observation and fracture morphology in the cghaz of a new 0cr18mo2ti ferritic stainless steel. Bulletin of Materials Science 25: 361-366.
12. Gojić M, Marijan D, TuDja M, Kožuh S (2008) Passivation of welded AISI 316L stainless steel Pasivacija varjenega nerjavnega jekla AISI 316L. Original Scientific Papers-Izvirni znanstveni članki Passivation of welded AISI 316L stainless steel 55: 408-419.