GALVANIC CORROSION IN GAS TUNGSTEN ARC WELDING OF 17-4 PH STAİNLES STELL
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Abstract

Galvanic corrosion occurrence among individual parts of a 17-4PH welded StSt in 3.5% NaCl was investigated. The results indicated that the most possible formation of galvanic couple is HAZ/weld where the HAZ acts as the anode and weld metal as the cathode. Potentiodynamic polarization measurement revealed that HAZ has the highest passive current density and the lowest pitting potential. Formation of several stable pits in HAZ has been reported. Zero Resistance Ammeter, ZRA also showed higher current density in weld/HAZ in compared to the base/HAZ and base/weld galvanic couples. The current densities were in the range of a few to tenths of nA/cm^2. Therefore, weld/HAZ couple has the highest risk of galvanic corrosion among the three individual couples.

Keywords: GTA welding, 17-4PH stainless Steel, galvanic corrosion, potentiodynamic polarization, ZRA measurement.

1. Introduction

Application of precipitation-hardened StSt are become more important [1-2] for their high strength and exceptional corrosion resistance [1-5]. The 17-4PH (AISI Type 630 or UNS S17400) StSt in this family is a martensitic StSt containing ca 3-5 wt.% Cu strengthened by the copper precipitation inside the temper lath martensitic matrix [3-6,7-9]. Gas tungsten arc welding (GTAW) process is commonly used to assemble StSt parts [10,11] and solidification processes during welding alters the microstructure and composition in weld heat affected zone (HAZ) [10-12] causing electrochemical dissimilarity of individual parts. This induces galvanic corrosion in weldment [10-12]. Researches on corrosion behaviour of 17-4PH StSt are scarcely available [13] and most of reports are based on measurements on unwelded and welded specimens rather than samples from individual parts of weldment [14, 15]. In this work, galvanic couples: weld-base and HAZ-base and weld-HAZ were studied by microscopic studies and potentiodynamic polarization measurements. Individual zones were cut and coupled potential and current density was measured by ZRA in 3.5%wt NaCl solution.

2. Materials and experimental methods

Sample was delivered in following conditions; solution treated at 1040°C for 1 hour and oil quenched, heat treated at 550°C for 4 hours and air cooled, reheating up 620 °C for 4 hours and then air cooled. A GTAW welding procedure was performed (ASME), using ER630 filler electrode. The welding parameters ; current 130-150 A, voltage 14-16 V, welding speed 180-200 mm/min. Argon with purity of 99.999 % with 11-14 lit/min flow rate was used. Identical samples of zones were obtained (Fig. 1), with 5x5 mm^2 cross-section area. ACM Instrument was used for the electrochemical tests in a 3.5%wt NaCl solution. Potentiodynamic polarization was done with a slow scan rate of 3 mV/min. Stable pitting morphology was examined by SEM. Coupled potential and current density of galvanic couples were measured by Zero Resistance Ammeter (ZRA) during one and 42 hours.

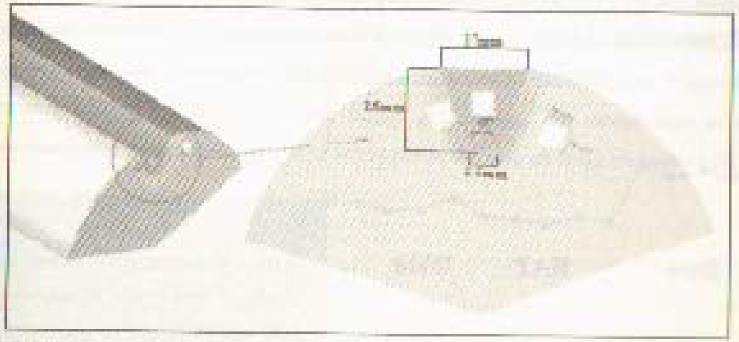

Figure 1. Schematic draw of weldment dimensions and individual sample extracted from base, HAZ and weld regions

3. Results and discussion

3.1. Microstructure characterization - As-received sample contains temper lath martensite and ferrite, shown in SEM image in Fig.2 [16]. After tempering stages, microstructure consists of recrystallized α-ferrite phase (appeared as white lamellar layer in Fig.2) formed in the tempered martensite. The presence of nano-size Cu-rich phase precipitates is also expected during the aging treatment that was previously reported by others [5]. The SEM image of the weld zone, Fig. 3, shows coarse and untempered lath martensite surrounded by strings of delta ferrite. Based on the micro-etch test, the extension of HAZ was 3 mm from untempered lath martensite, delta ferrite and coarse grains to fine grains and over aged martensite was observed [11, 13].

Figure 2. SEM image of microstructure of as-received 17-4PH stainless steel containing delta ferrite phase with white lamellar in shape and lath tempered martensite as a matrix.

Figure 3. SEM image of microstructure of weld region in GTAW of 17-4PH showing untempered martensite

Hardness measurement result, shown in Fig.4, reveals that hardness values decreases in weld and HAZ regions, attributed to the lack of Cu-rich phase precipitates and softening phenomena in weld and HAZ, respectively [11].

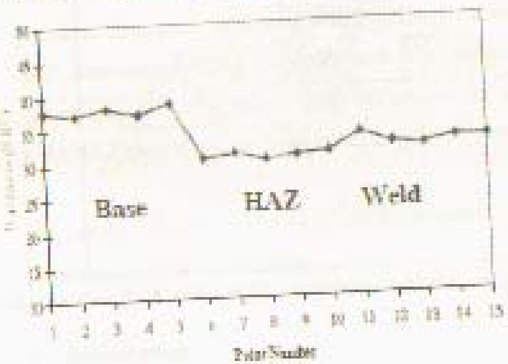

Figure. 4. Hardness profile measure along base, HAZ and weld region in repair welded 17-4PH stainless steel.

3.3. Potentiodynamic and potentiostatic measurements

The potentiodynamic polarization of individual base alloy, HAZ and weld zone sample for 17-4PH SSt are shown in Fig. 5. Clearly, the weld metal has the highest OCP value and the OCP of base is close to the weld zone. Moreover, corrosion rate calculation reveals that weld and base regions have more or less similar values while the corrosion rate of HAZ is several times of the base and weld regions. The results of pitting potential (breakdown potential) for all three zones of 17-4PH [illegible] show that the pitting potential of HAZ, base and weld are about -7, +50 and +130 mV vs. SCE respectively.

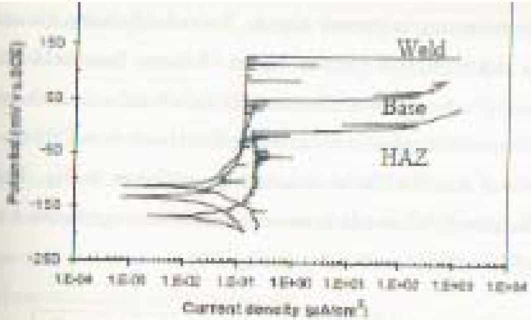

Figure 5. Potentiodynamic polarization curve for individual base, HAZ and weld regions of welded 17-4PH SStimmersed in 3.5% NaCl solution. Scan rate was 1 mV/min

This is an indication of lower pitting corrosion resistance in HAZ compared to base and weld zones. GTA welding operation decreases the passivity domain in HAZ. The average passivity current densities for three zones are 0.2, 0.13 and 0.13 $\mu A/cm^2$ for HAZ, base and weld zones, respectively. Therefore, HAZ shows slightly poor passivation behaviour. The existence of metastable pits could be also exhibited as current fluctuations in passivity range (Fig.5) which is more in HAZ indicating of lower pitting resistance associated to the HAZ in comparison to the other area. Figure 6 illustrate stable pits morphology in HAZ region after anodic polarization. The morphology of stable pits shows lacy cover over pits containing several micro pores showing network character [19].

Figure 6. SEM images of pitting morphology observed in HAZ zones after anodic polarization close to the pitting potential

3.4. ZRA measurements

The galvanic current densities were measured by ZRA method for the galvanic couples of base /weld, base/HAZ and HAZ/weld for 42 hours, shown in Fig.7. While the current density is slowly increases from about 32 to 66 nA/cm^2 in HAZ/weld couple, Fig.7(a), the corresponding couple potential is dropped down from -70 to -100 mV, Fig.7 (b). Decreasing in couple potential and simultaneously increasing in galvanic current density may be an indication of possible depolarization of anode, here HAZ, rather than depolarization of cathode or due to reducing nobleness of HAZ which in turn leads to increasing in current density. Remarkably lower current densities are observed for the weld/base and base/HAZ couples. Up to 18 hours, base/weld pair shows lowest current density below 1 nA/cm^2 whereas after this time, the base/HAZ couple shows the minimum value, Fig. 7(a). Both couple potential values are increasing from more than -200 to -7 mV and from -185 to -62 mV in weld/base and HAZ/base, respectively as shown in Fig. 7(b). Moreover, while the current density of the base/HAZ couple is remains almost constant below 1 to 2 nA/cm^2, it is gradually increased up to 7 nA/cm^2 in base/weld pair, Fig. 7(a).

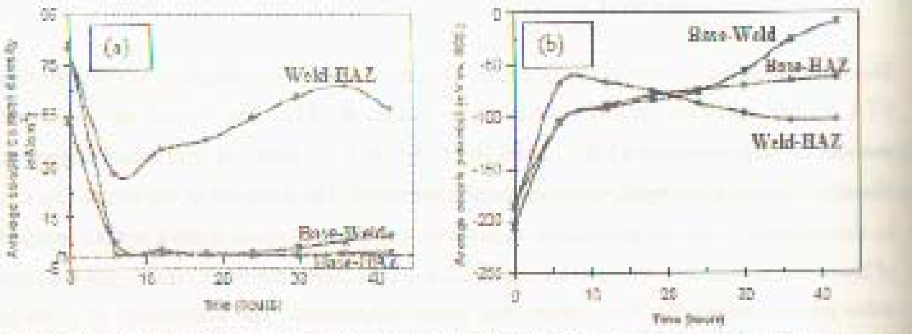

Figure 7. (a) Average galvanic couple current density and (b) average couple potential of three galvanic couples during 42 hours exposure time in 3.5% NaCl solution

In summary, the current densities of a few to tenths of nA/cm^2 were detected and the weld/HAZ couple has a highest driving force for galvanic corrosion occurrence and the highest risk among the three individual galvanic couples and two other possible galvanic cells, base/HAZ and base/weld couples, are almost harmless with negligible galvanic current of few nA/cm^2.

The overall current density which is measured by instrument in ZRA method in galvanic pairs can be attributed to the microstructure differences among three individual regions and can be divided to specific currents attributed to the local cathode and anode on the surface. Two differences, the type of martensite and amount of ferrite play the crucial role in galvanic corrosion occurrence.

Therefore, proper repair welding operation on 17-4PH stainless steel was performed. However the measured couple current is the average value on the whole sample surface area and may underestimate the galvanic current sustainable due to galvanic couple. In other word, the actual current in microscopical level are much more than the values measured by ZRA for the same area as it has been reported elsewhere by employing local probe technique, SRET [17]. Therefore, by generation of such this current, formation of stable pit in HAZ can be predicted after long term exposure. Furthermore, to eliminate the destructive influence of HAZ formation, proper heat treatment including solution annealing followed by an aging heat treatment can be suggested [20].

4. Conclusion

Galvanic corrosion occurrence among individual parts of a 17-4PH repair welded SS in 3.5% NaCl was studied. GTAW using ER630 filler metal was satisfactory. Galvanic current densities were a few to tenths of nA/cm^2 indicating sustainability of passivity. Potentiodynamic polarization measurement of pitting potential revealed that HAZ has the highest passive current density and the lowest pitting potential. Microscopical observation after anodic polarization confirmed formation of several stable pits in HAZ. ZRA also showed that weld/HAZ couple has the highest risk among the three individual galvanic couples.

5. Acknowledgement

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