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Corrosion Studies of Trimetallic Material in Synthetic Sea Water Environment

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Abstract: In the present study, the corrosion behaviour of trimetallic joint obtained from gas tungsten arc welding process in conventional mode and in pulsed mode has been investigated. The candidate materials for these studies are aeronautical steel AISI 4340 and austenitic stainless steel AISI 304L joined with filler ER309L. Potentiodynamic polarization studies were carried out on this trimetallic joints in synthetic sea water environment in order to understand the corrosion behaviour and corrosion rate. This investigation showed that the trimetallic joints obtained from pulsed current mode exhibited better corrosion resistance due to the presence of finer grains.
Keywords: Aeronautical steel; austenitic stainless steel; trimetallic material; Potentio-dynamic corrosion; Tafel.

1. Introduction

Austenitic stainless steel is one of the most versatile and widely used material due to its excellent strength, toughness and corrosion resistance in a wide variety of corrosive environments. AISI 304L steel joints are used for wide range of applications including defense, aerospace, automotive sector, petroleum refineries piping, offshore structural and piping applications, chemical industries, thermal and nuclear power plants [1-2]. As the name implies stainless steels have good corrosion resistance as an individual metal, but joining them can increase their susceptibility to localized corrosion because the process results in changes of microstructures and induces residual stresses [3-5].Aeronautical steel AISI 4340 owing to its high impact strength, superior fatigue properties and corrosion resistance; finds wide application in the field of aerospace parts such as landing gear, rocket mortar casings, turbine, nuclear and defense applications [6-8]. Combinations of aeronautical steel AISI 4340 and austenitic stainless steel AISI 304L are widely used in various aerospace and defense applications such as rocket motor casings, missile shells, armored vehicles, aircraft landing gears. Also, these types of joints are used in offshore structural and piping applications where they are prone to corrosion in the marine environment [9-10].

The fabrication of trimetallic material by employing pulsed current has been started in the past few years for obtaining grain refinement at the fusion zone. Many researchers reported that, the interface of trimetallic combination is more prone to corrosion due to formation of unwanted carbides and secondary phases. These phases affect the homogeneity of bimetal joint which induces the galvanic corrosion. The formation of secondary phases in this zone can be minimised by controlling the heat input [11].

Rajkumar et al. [12] has performed potentiodynamic polarization studies of aerospace materials MDN 250, AISI 4340 (EN24), Alloy 625 individual base materials in NaCl environment and reported that the corrosion rate was found to be more in AISI 4340. Mobin et al. [13] has performed electrochemical corrosion on mild steel and AISI 304L individual base material in synthetic sea water environment. Authors reported that the mild steel has increased corrosion rate than the AISI 304L.Further they reported AISI 304L has not shown any trace of localized corrosion.

Corrosion aspects related to bimetallic combinations is addressed by many researchers. Narayanan et al. [14] conducted the studies on bimetallic combination of Monel 400 and AISI 304 stainless steel exposed under high temperature molten salt environments. The authors reported that the base metal Monel 400 was unaffected during the corrosion runs. Mohandas et al. [15] employed both the conventional mode and pulsed mode of gas tungsten arc technique for ultra-high strength steel. Author reported the enhancement of corrosion properties using pulsed mode; due to finer grain size. Arivarasu et al. [16] investigated the hot corrosion studies on bimetallic combination of stainless steel 304 and low alloy steel 4140 in the molten salt environment. They have noticed accelerated corrosion due to intense spalling and sputtering of scale in the interface as compared to corresponding candidate materials. Investigations on the dissimilar joints subjected to electro chemical corrosion studies have been reported by various researchers. Deen et al. [17] has investigated the corrosion properties on the bimetallic combination of low carbon steel (ASTM A516) and EM12K from Submerged Arc technique. Authors have performed potentiodynamic corrosion testing under the NaCl environment and reported that the fusion zone has least corrosion resistance than the base metal. Jianyu et al. [18] has carried out electrochemical corrosion testing on AISI 316 and AISI 2205 joints and reported that the fusion zone of the AISI 316 showed more corrosion resistance than the AISI 2205 whereas the reverse is in the case of base materials. The electrochemical potential gradient is developed in adjacent sites of a bimetallic\trimetallic joints because of the microstructural changes that occurs during the joining process.

Potentio-dynamic corrosion studies under synthetic sea water environment on these particular AISI 4340 and AISI 304L joints obtained from pulsed current GTA process using ER309L filler wire were not found in the available open literature. This trimetallic combination is found in the rocket motor casings, missile shells and defense applications. Rockets and missiles post mission scenario and defense aircrafts in emergency situations are designed to fall/land in sea and is restored from sea after several days/weeks, where it starts to corrode. During this period, joints will be subjected to corrosion in the sea water environment. Therefore, it is utmost important to understand the corrosion behaviour of these weldments when they are subjected to such an environment. In this attempt, accelerated corrosion testing is done in order to evaluate the behaviour of these materials in synthetic sea water environment.

2. Experimental procedure

2.1 Candidate materials

The samples used for these studies are trimetallic materials of AISI 4340 and AISI 304L employing both continuous and pulsed gas tungsten arc technique using ER309L filler. The chemical composition of individual materials is represented in Table. 1.

Table. 1 Chemical composition, equivalent atomic weight and density of the base and filler metals

	Chemical Composition (% by Weight)								
Base/Filler Metal	**C**	**Si**	**Mn**	**Cr**	**Ni**	**Mo**	**Fe**	**Density**	**Eq. Atomic weight**
AISI 4340	0.310	0.23	0.64	0.98	1.34	0.23	Bal.	7.85	55.7322
AISI 304L	0.037	0.46	0.95	19.14	8.35	0.17	Bal.	8.00	55.2618
ER309L	0.020	0.50	1.70	24.00	13.2	-	Bal.	7.95	55.1454

2.2 Sample preparation and microstructural examination

Corrosion samples were cut to required dimensions of 40 x 20 mm using Electrical Discharge Machining (EDM). The samples were polished using standard metallographic procedure with SiC emery sheets followed by disc polishing with alumina slurry and is shown in Fig 1. The cross section of the fusion zone is etched with mixed etchant consisting of HCl (15ml) + HNO_3 (10 ml) + $C_2H_4O_2$ (10 ml). The samples were examined using Carl Zeiss optical microscope for microstructures.

2.3 Electrochemical measurements

Potentio dynamic corrosion studies were performed at ambient temperature using an electrochemical corrosion analyzer (Make: CH instruments). Experimental setup of the corrosion testing is represented in Fig. 2.

The area exposed for the corrosion testing was 1 cm^2 each covering the complex zone consisting of AISI 4340+E309L+AISI 304L in both the samples. The samples were tested in synthetic sea water environment prepared in accordance with the ASTM D1141-2013 [19] whose chemical composition is represented in Table. 2. A conventional three-electrode assembly was used to carry out the electrochemical experiments. The candidate specimen that is exposed to 1 cm^2 dimension was used as working electrode; a platinum wire as a counter electrode and a saturated calomel electrode (SCE) via luggin capillary probe as a reference electrode. The luggin capillary was kept in a manner that its tip is very close to the working electrode to minimize IR drop. The working electrode was first immersed in the corrosive medium for 20 min to access a steady state open circuit potential (OCP). After this time, the steady state OCP corresponding to the corrosion potential of the working electrode was obtained. Potentiodynamic polarization curves were obtained by changing the electrode potential from the cathodic to anodic direction (OCP ± 200 mV) with a scan rate of 1 mV s^{-1}. The anodic and cathodic curves of linear Tafel plots were extrapolated to obtain the corrosion current (I corr) and corrosion potential (Ecorr) and are listed in Table 3.The corrosion analysis is done based on the Tafel's method and the corrosion rate in Mils per year (mpy) for the each individual samples is found out.

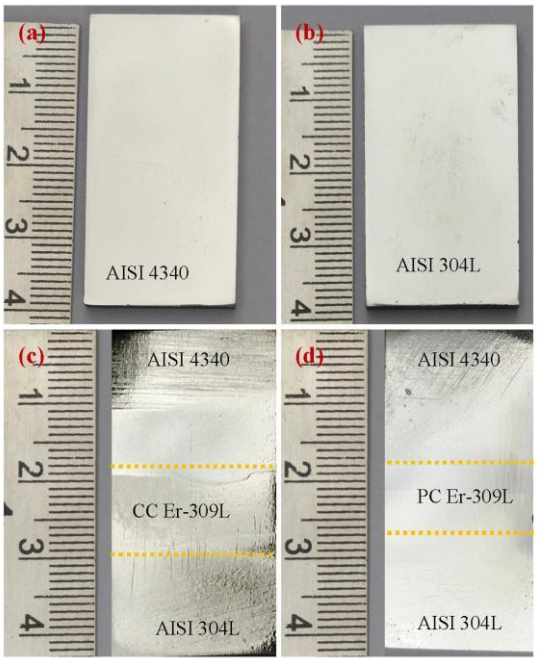

Fig.1 Photographs showing samples prepared for potentiodynamic corrosion studies (a) Base material AISI 4340 (b) Base Material AISI 304L ; Trimetallic material AISI 4340 + E309L + AISI 304L made using (c) Conventional mode GTA technique (d) Pulsed mode GTA technique

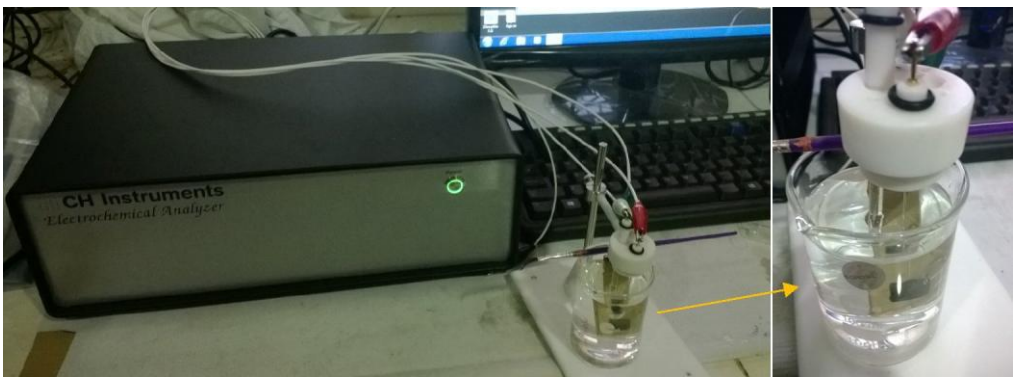

Fig.2 Experimental Setup showing the samples subjected to Potentiostat corrosion studies

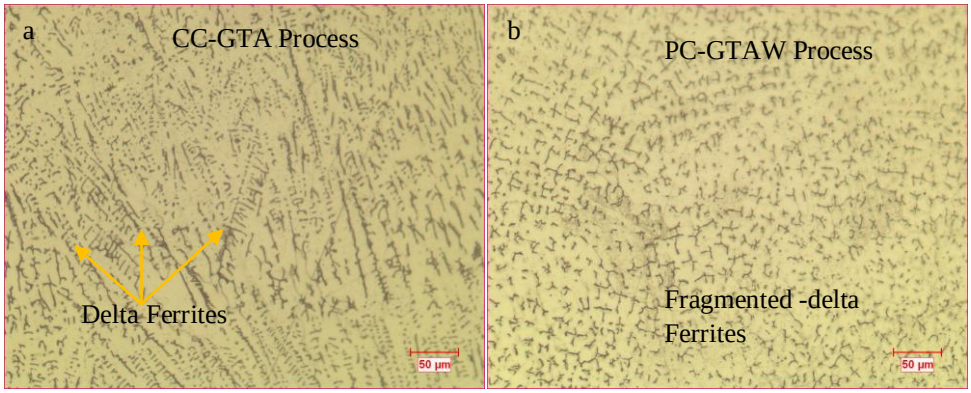

Fig. 3 Microstructure at the fusion zone of the trimetallic AISI 4340+E309L+AISI 304L material made with a) GTA process b) PC-GTA process

Table. 2 Chemical composition of synthetic sea water [A]

Compound	Concentration, g/L
NaCl	24.53
$MgCl_2$	5.20
Na_2SO_4	4.09
$CaCl_2$	1.16
KCl	0.695
$NaHCO_3$	0.201
KBr	0.101
H_3BO_3	0.027
$SrCl_2$	0.025
NaF	0.003

[A] The pH was after adjustment with 0.1N NaOH was 8.2

Table.3 Cumulative table representing corrosion current density (I corr), corrosion potential (E corr) and Corrosion rate

Material	I_{Corr} A (µA)	E_{corr} mV	Corrosion Rate Mils per year (mpy)
GTAW (Er309 L)	1.760×10^{-4} (176.000)	-590	78.54
PCGTAW (Er309 L)	9.997×10^{-7} (0.9997)	-555	0.4462

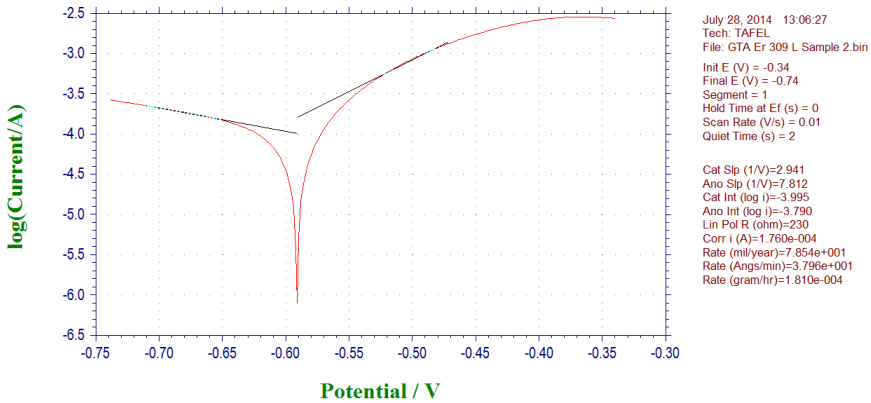

Fig.4 Tafel polarization curves for the joint AISI 4340+ AISI 304L made using ER309L filler by Conventional GTA process immersed in synthetic sea water environment

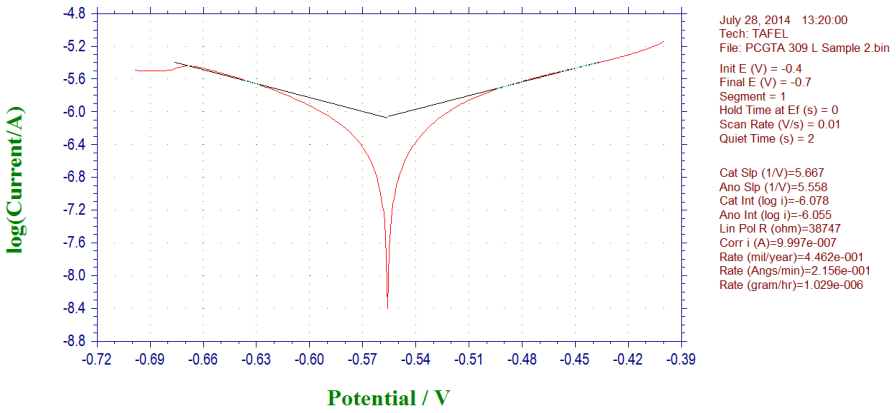

Fig. 5 Tafel polarization curves for the joint AISI 4340+ AISI 304L made using ER309L filler by pulsed mode GTA process immersed in synthetic sea water environment

3. Results and discussion

The microstructure examination (Fig.3a) shows the delta ferrite formation in the fusion zone in the conventional current process, whereas in the pulsed mode (Fig. 3b) the delta ferrite obtained is fragmented. Controlled cooling due to the current pulsing has resulted in the fragmentation of the delta ferrite. Tafel polarization curves plotted for trimetallic material made by continuous and pulsed current GTA technique immersed in synthetic sea water environment is represented in Fig. (4 - 5).On analyzing the graphs that the corrosion current density (**I_{corr}**) was found to be 176.00 µA for the GTA process while that for the pulsed mode it is 0.9997 µA. Further, the corrosion potential (**E_{corr}**) was found to be -590mA and -555mA respectively. The corrosion rate of the trimetallic samples made with continuous and pulsed mode are found to be 78.54 mils/year and 0.4462 mils/year respectively. The corrosion resistance of the trimetallic sample employing pulsed mode joining process is higher as compared to the conventional mode. The delta ferrite is an undesirable phase in the corrosion aspect; since the delta ferrite is fragmented in the current pulsing the rate of corrosion is reduced. The results are also opined with many researchers [14, 15]. Authors have reported that the pulsed mode technique producing a fine grained structure without segregation/deleterious phases. In addition, this could be also due to the heat input for the pulsed mode is comparatively less than continuous current GTA technique.

4. Conclusion

This paper has provided comparison of the corrosion behaviour for the trimetallic joint made by conventional GTA process and pulsed mode of GTA process. From the experimental investigation the below mentioned conclusions can be made.

1. Corrosion current density I_{corr} for the trimetallic made by conventional GTA process (176 µA) > pulsed mode of GTA process (0.9997 µA).
2. Corrosion potential I_{corr} for the one made with GTA process (-590 mV) > pulsed mode of GTA process (-555mV).
3. Rate of corrosion for the trimetallic in synthetic seawater environment made conventional GTA process is more (78.54 mpy) than the one made with pulsed mode of GTA process (0.4462 mpy).
4. With the above mentioned observations, it is concluded that the trimetallic joint involving AISI 4340 +E309L+AISI 304L obtained from pulsed current mode of GTA process is best suited in the corrosive sea water environments.

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