International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.9, No.04 pp 350-356, 2016

Effect of oxide layer and activating flux on corrosion behavior of TIG welding of 304 austenitic stainless steel weldments

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Abstract: This work has been dedicated to study the influence of thin oxide layer on base material surface and the activating flux on the weld bead geometry of AISI 304 stainless steel TIG weldments. In this study, two types of base material surface condition namely natural and oxidized surface has been used. Sodium silicate paste (commercial grade) was used as an activating flux in this study. All the TIG and A-TIG welds were analyzed to study the corrosion behavior of weld bead geometry were determined by using potentio dynamic polarization test. The results indicated that the specimens welded with oxidized surface showed minimum rate of corrosion when compared to conventional TIG and A-TIG welded specimens. The corrosion rate has been clearly observed for base material is = $9.117*10^{-7}$ mm/yr and for the specimen welded with natural condition is $2.168*10^{-7}$ mm/yr. The corrosion rate of specimen welded with oxidized plate condition was observed as $2.091*10^{-7}$ mm/yr and corrosion rate of the A-TIG welded specimen was observed as $3.016*10^{-7}$ mm/yr.
Keywords: Activating flux; A-TIG welding; corrosion behavior; Austenitic stainless steel.

1. Introduction

Corrosion is the main factor which impacts nation financially by damaging the materials in chemical and food processing equipments. Analyzing the rate of corrosion is essential for protecting the welded joints used in austenitic stainless steel materials. The AISI 304 stainless steel is extensively used in industry due to its superior low temperature toughness and corrosion resistance. The use of stainless steels has been growing steadily and new areas of application, often in demanding service environments, are constantly being developed. The serviceability of stainless steels in many of these applications is determined by the material properties of the steels and how they perform when exposed to different service environments. It has excellent corrosion resistance in a wide range of atmospheric environments.

So it is used in manufacturing of food processing equipments, chemical containers and heat exchangers Gas tungsten arc welding (GTAW), also called tungsten inert gas welding (TIG), is one of the main welding methods which has been widely used in industry for the welding of stainless steel, titanium alloy, and other nonferrous metals for its high weld quality, lower sensitivity to the joint fitting and welding parameters, and lower equipment investment. The A-TIG process has been identified to improve production efficiencies in a wide range of industries in the former Soviet Union, including power generation, chemical and aerospace. Activating flux is a mixture of inorganic material suspended in a volatile medium. A thin layer of flux is applied on the surface of the joint to be welded by brush before welding the weldments. Many research articles have been reported in corrosion behavior of austenitic stainless steels the corrosion potentials of the steel mostly depends on the cathodic reaction involved in oxido-reduction process between the elements like Fe, Cr and Ni of steel and oxidizing species of medium [1].

The microstructure and uniform corrosion behavior of type 316 stainless steel weld metals have been correlated by varying the concentrations of Cr, Mo and different contents of ferrite. The results showed that most of the electrochemical parameters were unaffected by changes in the heat input. But there existed a correlation between the corrosion rate and the *E*pp (passivation potential value). It was found that as the *E*pp became more active, corrosion rates drastically decreased. [2]. The tribological behavior, X-ray peak broadening, and microstructure changes of AISI 1045 carbon steel and AISI 304 stainless steel samples were reported under simultaneous wear and corrosion. The high wear rates of carbon steel and stainless steel samples, of order 10^{-3} to 10^{-4} mm^3/N m, could be due to the synergetic effects of different wear mechanisms, such as mechanical, oxidation, and corrosive wear[3].

The corrosion behavior of stainless steel weldments is welded by TIG and Electron Beam welding techniques were reported. The results indicated that the sample welded by EB technique showed the best corrosion behavior whereas the samples welded with TIG process showed less favorable behavior [4]. The pitting and galvanic corrosion behavior of laser beam welded stainless steel weldments are such as 304 and 316. The results proved that the welds exhibited passivity and the pitting corrosion resistance was reduced due to lower pitting potential and a higher corrosion current density compared with those of the base metal [5]. The influence of weld metals on corrosion behavior of dissimilar metals like AISI 304 and DHP copper are in sea water environment [6]. The effect of pitting corrosion rate of AISI304L is welded by pulsed current plasma arc welding. The results indicated that peak current was the most influencing factor on the pitting corrosion rate [8]. Cyclic polarization tests performed to study the corrosion behavior of duplex stainless steels proved that the different morphologies of thermally activated and formed secondary austenite, unlike eutectoid secondary austenite, did not influence the pitting corrosion resistance significantly [9]. The study on the influence of isothermal and quenching in nitrides on super duplex stainless steel showed that the corrosion resistance of the austenite phase was largely reduced by isothermal nitrides, while the quenched-in nitrides reduce the corrosion resistance of the material to a much lesser extent[10]. The effect of pulsed TIG welding process parameters on pitting corrosion resistance of 304L Stainless steel is welds [12]. Loss of strength where the cross section of structural members is reduced by corrosion, leading to a loss of strength of the structure and subsequent failure[7]. So it is essential to study the corrosion behavior of welded structures. Keeping the above literature survey, the objective of the present work is to study the effect of the oxide layer on the surface to be welded and the activating flux on the corrosion behavior of austenitic stainless steel 304.

2. Materials and Methods

2.1 Base and filler materials

The AISI 304 stainless steel plate of size 150 mm x 100 mm x 6.5 mm has been used as base material for this study. The chemical composition of AISI 304 stainless steel is listed in Table 1.

Table 1 Chemical composition of 304 Austenitic Stainless Steel (% wt)

Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Nb	V
71.4	0.039	0.294	1.16	0.037	0.007	18.26	0.400	8.48	˜0.25	0.0338	0.0806

2.2 Experimental procedure

The welding has been done using bead-on-plate in a flat position without filler metals. The power source was used with Direct Current-Electrode Negative (DCEN) polarity with mechanized system in which the test piece was moved at a constant speed. A water-cooled normal torch with a thoriated tungsten electrode (W–2% ThO_2, 1.6

mm diameter) was used for the experiments. The vertex angle of the electrode was 60°. The welding parameters used for the investigation are listed in Table 2.

Table 2 Welding parameters

Welding Parameters (Units)	Values
Current (A)	100
Voltage (V)	13
Arc Length (mm)	1.6
Gas Flow Rate (lpm)	10
Arc Travel Speed (mm/min)	100

For heat treatment of a base material, an electric furnace has been used and heat treatment done on 304 stainless steel plate of thickness 6.5 mm for formation of thick oxide layer (oxidation process) on the surface of the plate. The plate was heated to 1000 $^{\circ}$C, soaked for one hour and subjected to air cooling process. 304 Stainless steel plates with oxide layer formation are shown in Fig. 1.

The end profile of the tungsten electrode was grinded as conical type. The gas cutting was used for cutting the base material as per above mentioned dimensions. Using a hand grinding wheel machine, the edges and the surface of the plate were polished. The plates were cleaned with acetone for removal of grease and oil particles just before welding**.**

Initially, the melt runs were welded by the conventional TIG welding process with the given welding parameters without applying the activating flux. The bead on plate weld runs has been performed in natural and oxidized conditions with electrode diameter as 1.6mm. After finishing the conventional TIG process, the melt runs were produced with the activating flux. Before welding, a thin layer of Na_2SiO_3 flux powder was applied on the regions in the plates to be welded using a thin wire brush.

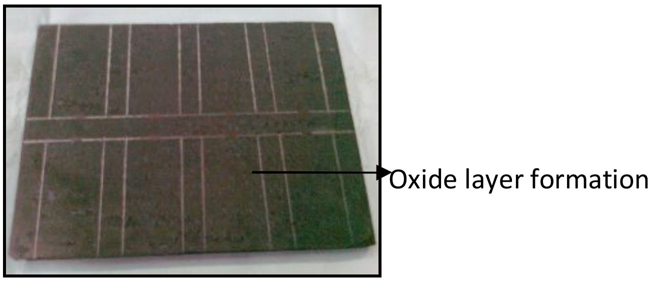

Fig. 1 Stainless steel plate with oxide layer on its surface.

In this study, the shape of electrode tip profile was used namely conical profile. The electrode has been shaped according to the standard procedure as shown above. The electrode tip profile after finishing A-TIG melt runs as such are shown in Fig. 2.

Fig. 2 Conical tip profile of 1.6mm electrode diameter.

The potentiodynamic polarization tests were performed by using a computer controlled ACM 1393 series Gill AC potentiostat. In this experiment, the sample was connected to working electrode (WE 1), platinum electrode was connected to auxiliary electrode (AE) and the calomel electrode was connected to reference electrode (RE). The cell settle time was given as 15sec and the sweep rate 60 mV/min was used. An exposure area of 19.634 mm^2 with a circular diameter of 5 mm was considered for polarization tests.

Corrosion tests were performed in chloride solution of 3.5% NaCl. The specimens after the electrochemical experiment were examined to assess the corrosion nature on the surfaces. The corrosion current was calculated by using Tafel extrapolation technique.

3. Results and Discussions

All the specimens were taken for analyzing the Icorr value, rest potential and the rate of corrosion by PDP analysis. The Tafel extra polarisation curve has been obtained for each welded specimen and the base metal.

Fig. 3 shows the corrosion pattern obtained for 304 base materials. The i_{Corr} was observd as $8.88x10^{-5}$ mA/cm^2 , the Rest potential value was -220.99 and the rate of corrosion $9.117x10^{-7}$ mm/yr. The highest rate of corrosion has been obtained in unwelded 304 specimen.

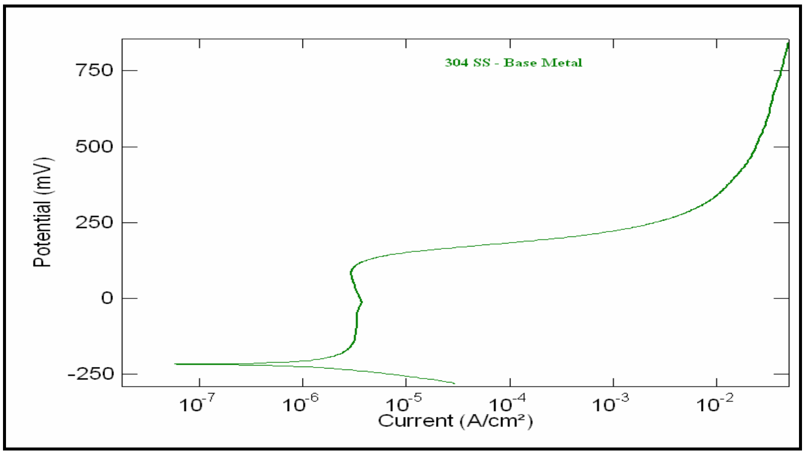

Fig. 3 Corrosion pattern of 304 SS base material

Fig. 4 shows the corrosion pattern obtained from the tafel couve for the specimen welded with conventional TIG welding. The type of surface condition of specimen is natural with 1.6mm electrode diameter. This specimen having the i_{Corr} value as $2.929x10^{-5}$ mA/cm^2 and the rest potential was observed as -193.85 and Corrosion rate was $3.007x10^{-7}$ mm/yr.

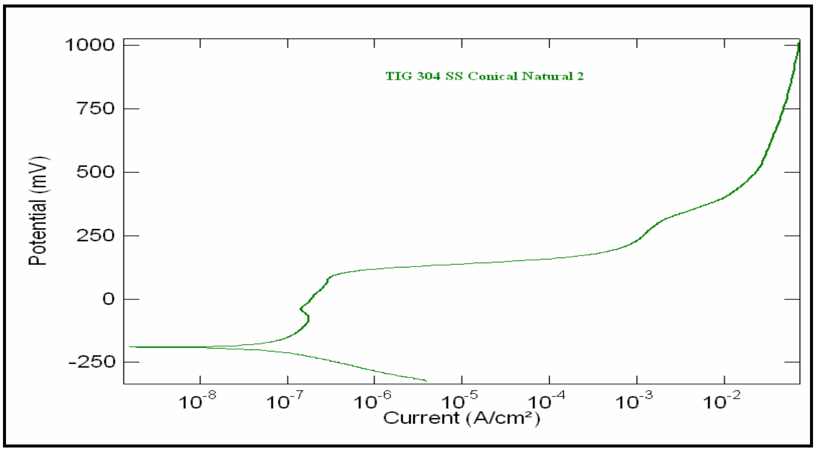

Fig. 4 Corrosion pattern of TIG welded 304 SS

Fig. 5 shows the tafel polarisation curve obtained for the corrosion rate of the specimen welded with natural surface condition and the electrode diameter was 2.4mm. The i_{Corr} value for this specimen was observed as $2.112*10^{-5}$ mA/cm^2 and the rest potential was 5.7921. the rate of corrosion was observed as $2.168*10^{-7}$ mm/yr.

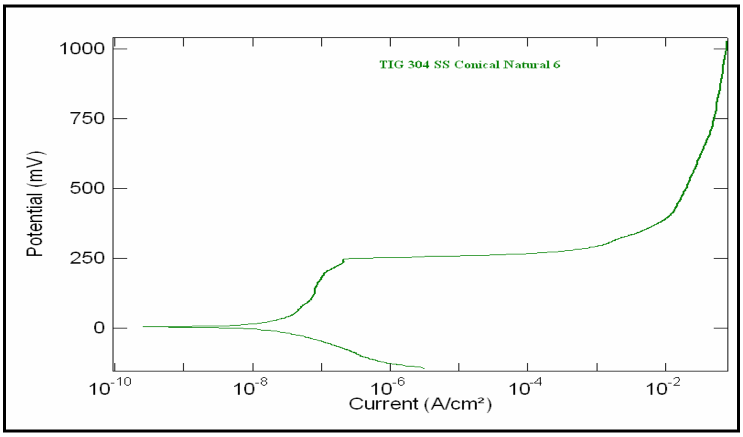

Fig. 5 Corrosion pattern of TIG welded 304 SS

Fig. 6 shows the tafel polarisation curve obtained for the corrosion rate of the specimen welded for the formation of thin oxide layer on the surface with electrode diameter is 1.6mm. The i_{Corr} value for this specimen was observed as $2.037x10^{-5}$ mA/cm^2 and the rest potential was 1.9232. the rate of corrosion was observed as $2.091x10^{-7}$ mm/yr.

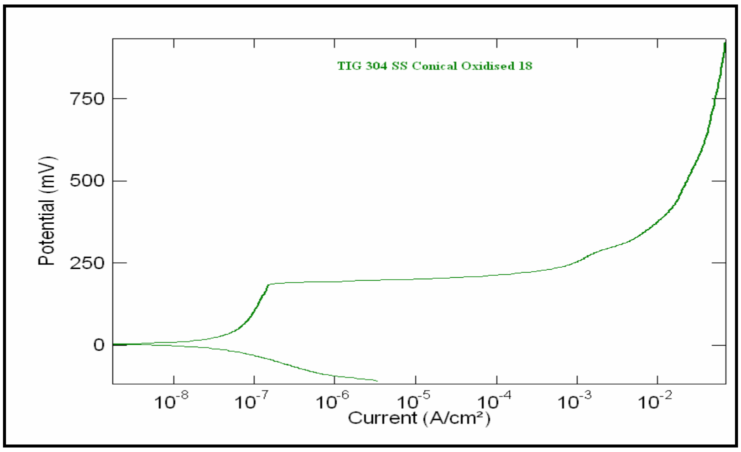

Fig. 6 Corrosion pattern of TIG welded of oxidised condition 304 SS

Fig. 7 shows the tafel polarisation curve obtained for the corrosion rate of the specimen welded for the formation of thin oxide layer on the surface with electrode diameter is 2.4mm. The i_{Corr} value for this specimen was observed as $2.778*10^{-5}$ mA/cm^2 and the rest potential was -260.72. the rate of corrosion was observed as $2.852*10^{-7}$ mm/yr. The corrosion resistance of a stainless steel is dependent on the presence of a protective oxide layer on its surface[7]. The corrosion rate was reduced in the case of oxide layer formation on the surface of specimen.

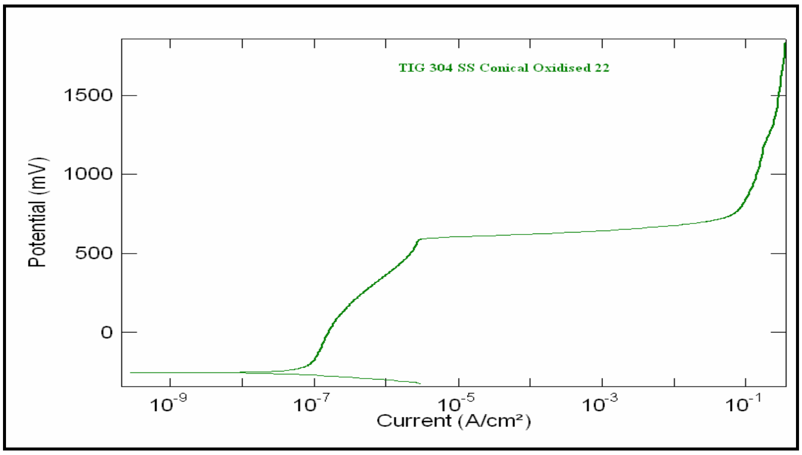

Fig. 7 Corrosion pattern of TIG welded of oxidised condition 304 SS

Fig. 8 shows the corrosion pattern of A-TIG welded specimen. The electrode diameter used in this specimen is 1.6mm. The i_{Corr} value has been obtained as $2.938*10^{-5}$ mA/cm^2 and rest potential was -83.844. The corrosion rate of the specimen coated with activating flux was observed as $3.016*10^{-7}$ mm/yr. The electrode diameter used in this specimen is 2.4 mm. The i_{Corr} value has been obtained as $3.377*10^{-5}$ mA/cm^2 and rest potential was -1.4138. The corrosion rate of the specimen coated with activating flux was observed as $3.467*10^{-7}$ mm/yr. Austenitic steels have a better resistance to oxidation since the presence of chromium and mixed chromium–iron oxides in an oxide layer makes it more protective than a pure iron oxides layer [11]. So, the rate of corrosion was observed less compared with base material and specimens welded with conventional TIG welding.

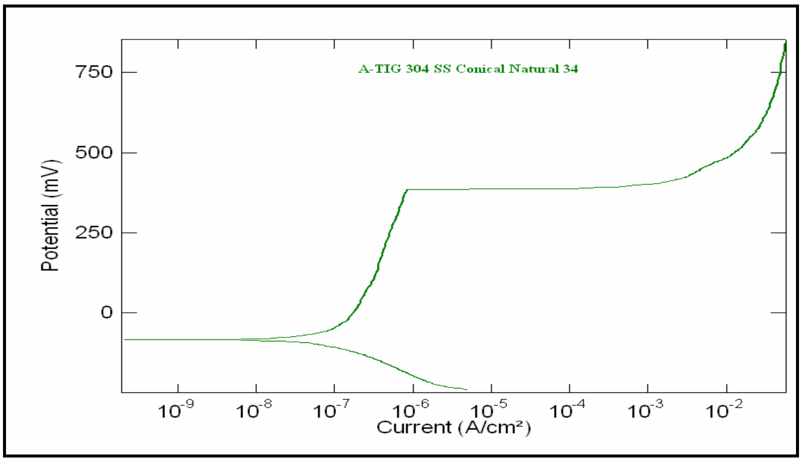

Fig. 8 Corrosion pattern of A-TIG of 304 SS

5. Conclusions

The corrosion rate of base metal and the welded samples have been estimated by using PDP analysis. The Tafel polarization curve for the corrosion behavior of all the specimens was obtained. From the bead-on-plate test and the analysis of the corrosion characteristics of the weld, these main conclusions were drawn.

1. The lowest rate of corrosion has been obtained in the welded sample with oxidized condition due to the oxide layer formed on the surface of the plate.
2. The highest corrosion rate has been observed in the base metal specimen. The corrosion rate was obtained as $9.117x10^{-7}$ mm/yr.
3. The rate of corrosion was observed in the specimen welded by A-TIG process as $3.016*10^{-7}$ mm/yr for the electrode diameter of 1.6 mm.

4. The oxygen content plays an important role in the corrosion behaviour of austenitic stainless steel weldments.

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