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Effect of pulsed gas tungsten arc welding on corrosion behavior of Ti–6Al–4V titanium alloy

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Abstract

Due to the excellent combination of properties such as elevated strength-to-weight ratio, high toughness and excellent resistance to corrosion, make titanium alloys attractive for many industrial applications. Advantages of pulsed current welding frequently reported in literature include refinement of fusion zone grain size, etc. Hence, in this investigation an attempt has been made to study the effect of pulsed current Gas Tungsten Arc (GTA) welding parameters on corrosion behavior of Ti–6Al–4V titanium alloy. Pulsed current gas tungsten arc welding was used to fabricate the joints. To optimize the number of experiments to be performed, central composite design was used. The investigation revealed increase in corrosion resistance with increase in peak current and pulse frequency up to an optimum value of the same and decrease in corrosion resistance beyond that optimum point. An increase in corrosion resistance with grain refinement was also detected.

Keywords: Pulsed current; Gas tungsten arc welding; Titanium alloy; Corrosion rate

1. Introduction

Localized corrosion, which usually appears as pitting or crevice is a multi-step process. It is generally accepted that the following four steps are involved in localized corrosion: (i) adsorption of the reactive anion on the oxide covered titanium; (ii) chemical reaction of the adsorbed anion with the titanium ion in the titanium oxide lattice or the precipitated titanium hydroxide; (iii) thinning of the oxide by dissolution; and (iv) direct attack of the exposed metal by the anion perhaps assisted by an anodic potential. This is some times called pitting propagation [1–3].

Because of their high chemical activity, titanium alloys are easy to absorb harmful gas and many problems such as low mechanical properties and unstable structure would result [4–6], hence Gas Tungsten Arc Welding (GTAW) is a usually preferred method. The drive to improve the weld quality associated with improvement in process parameters demands the use of improved welding techniques and materials. Unfortunately, welding of titanium alloy leads to grain coarsening at the fusion zone and heat affected zone (HAZ) [7,8]. Weld fusion zones typically exhibit coarse columnar grains because of the prevailing thermal conditions during weld metal solidification [8].

Ti–6Al–4V also have excellent specific tensile and corrosion resistance, mainly used for aircraft structural and engine parts, material for petrochemical plants and surgical implants. It has been reported that pulsed current variation results in grain refinement in mild steel, stainless steel, aluminium alloys and titanium alloys [9–11]. However, reported research work on relating the pulsed current parameters and fusion zone microstructure and corrosion behavior are very scanty.

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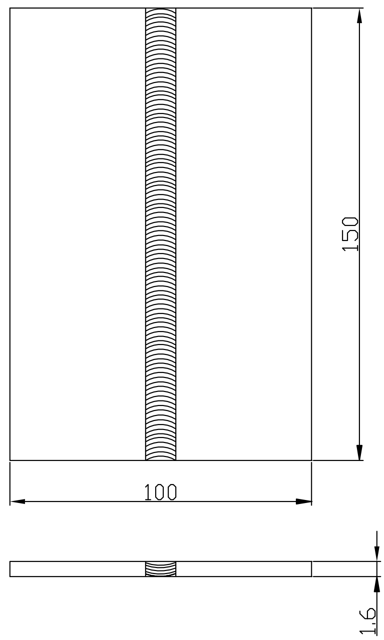

(All the dimensions are in mm)

Fig. 1. Dimensions of joint configuration.

Table 1
Important factors and their levels

Coded levels	Peak current P (A)	Base current B (A)	Pulse frequency F (Hz)	Pulse on time T (s) (%)
−2	60	20	0	35
−1	70	30	3	40
0	80	40	6	45
1	90	50	9	50
2	100	60	12	55

Table 2
Chemical composition (wt%) of the base metal

Elements	Al	V	C	Fe	O	N	H	Ti
% by weight	6.3	4	0.006	0.17	0.166	0.006	0.002	Balance

Table 3
Mechanical properties of base metal

Ultimate tensile strength (MPa)	Notch tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Vicker's hardness (0.5 kg)	Charpy impact test (J)
998	1146	910	10	320	18

2. Methodology

2.1. Material and welding

The predominant factors which are having greater influence on fusion zone grain refinement of pulsed current GTA welding process have been identified from the literature survey [12–15]. They are peak current, background current, pulse frequency and pulse on time. The mill annealed sheets of Ti–6Al–4V titanium alloy were cut into the required sizes ($100 \times 150 \times 1.6$ mm). Square butt joint configuration, as shown in Fig. 1 was prepared to fabricate autogenous pulsed current GTAW joints. The initial joint configuration was obtained by securing the plates in position using tack welding. Since the plate thickness is 1.6 mm, the single pass welding procedure has been followed to fabricate all the joints. All necessary care was taken to avoid joint distortion and the joints were made after securing the plates with suitable clamps.

Large number of trial runs has been carried out using 1.6 mm thick sheets of titanium (Ti–6Al–4V) alloy to find out the feasible working limits of pulsed current GTA welding parameters. Different combinations of pulsed current parameters have been used to carry out the trial runs. The bead contour, bead appearance and weld quality have been inspected to identify the working limits of the welding parameters given in Table 1. Further details of observations made on trial runs and mathematical modeling are given elsewhere [15].

2.2. Conduct of the experiments

The base metal used in this investigation is a high strength titanium alloy of Ti–6Al–4V grade. By considering all of the above conditions, the feasible limits of the parameters have been chosen in such a way that the Ti–6Al–4V alloy should be welded without any weld defects. Due to a wide range of factors, it was decided to use four factors, five levels, rotatable central composite design matrix to optimize the number of experiments. The chemical composition of the base metal was obtained using a vacuum spectrometer (ARL-Model: 3460). Sparks were

(a) Potentiostat (b) Set up

Fig. 2. Photographs of potentiostat used for corrosion test.

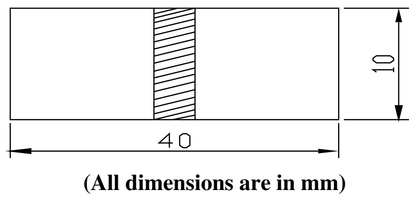

Fig. 3. Dimension of specimen for testing.

ignited at various locations of the base metal sample and their spectrum was analyzed for the estimation of alloying elements. The chemical composition and mechanical properties of the base metal are presented in Tables 2 and 3, respectively. The specimens for corrosion test were prepared following the metallographic procedures. Final polishing was done using the diamond compound (1 μm particle size) in the disc polishing machine. Specimens were etched with Krolls etchant to reveal the microstructure.

2.3. Corrosion measurements

The polarisation studies of the welds were carried out in non-deaerated 3.5% NaCl solution of pH 7. Analar grade chemicals and double distilled water were used for the preparation of the electrolyte. The photograph of the potentiodynamic polarisation set up is shown in Fig. 2. A potentiostat (Gill AC) was used for this study in conjunction with an ASTM standard cell and personal computer. The specimens were prepared as per the metallographic standard. Specimens of 10×40 mm (width and length), Fig. 3, were prepared to ensure the exposure of 5 mm diameter circular area in the weld region to the electrolyte. The rest of the area was covered with an acid resistant lacquer. The corrosion

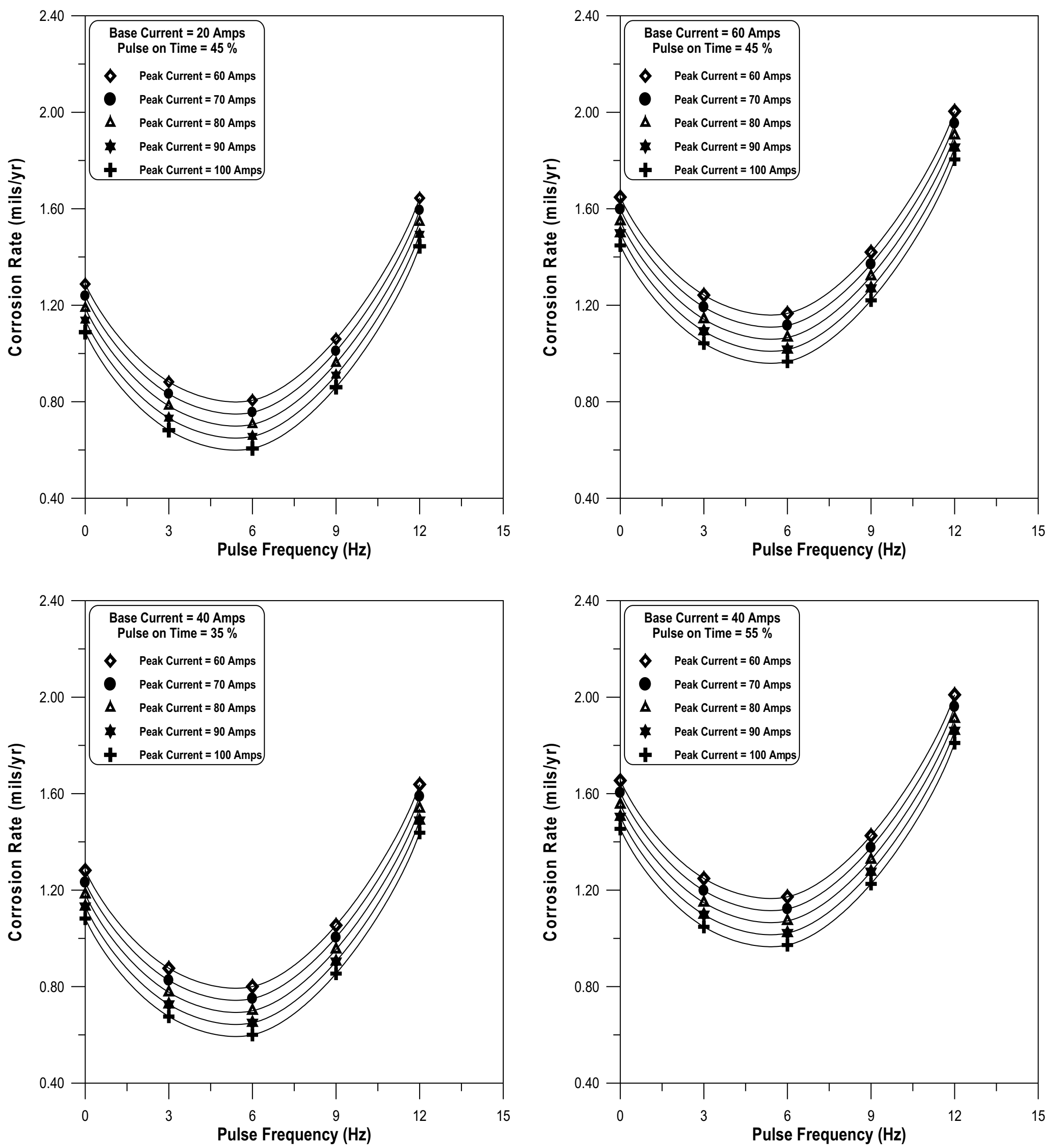

Fig. 4. Effect of pulse current parameters on corrosion rate.

rate was calculated by polarizing the specimen anodically and cathodically and by extrapolating the tafel regions of anodic and cathodic curves to the corrosion potential.

3. Results and discussion

The maximum and minimum value of corrosion rate obtained during the experimentation of 31 samples using central composite design was 3.18 and 0.51 mils/yr, respectively.

Fig. 4 shows the effect of pulsing current parameters on corrosion rate. The corrosion rate of the Ti–6Al–4V alloy has been predicted for various combinations of the pulsing current parameters. Graphs are plotted taking pulse frequency and corrosion rate in '*X*' and '*Y*' axis, respectively. Corrosion rate is plotted for various frequencies taking the factor pulse on time constant for different base current values. The following important observations can be made from the graphs shown in Fig. 4.

- It is observed that the corrosion rate tends to decrease between the pulse frequencies of 0 and 6 Hz. The corrosion rate is observed to increase between the pulse frequencies of 6 and 12 Hz.
- The corrosion rate takes an increasing trend by 59.4% for change of base current by 200%, measured at constant pulse on time of 45%.
- The corrosion rate value is on the higher side by 62% for an increase of pulse on time by 57%, observed at constant base current of 40 A.
- A decrease in corrosion rate is experienced for an increase of peak current from 60 to 100 A irrespective of changes seen in base current and pulse on time.

3.1. Discussion

The photomicrographs exhibited many etched grain boundaries. When the Fe content is low, the Fe will accumulate at the grain boundaries, but in insufficient quantities to stabilize significant amount of β phase. Consequently, during fabrication, if grain growth is unchecked a coarse grained material is obtained, which leads to reduction in corrosion resistance.

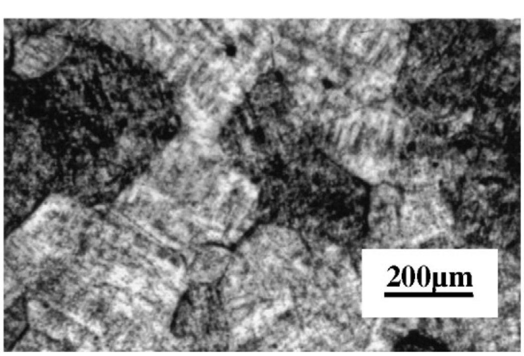

Fig. 5. Microstructure of weld fusion zone showing equi-axed grains.

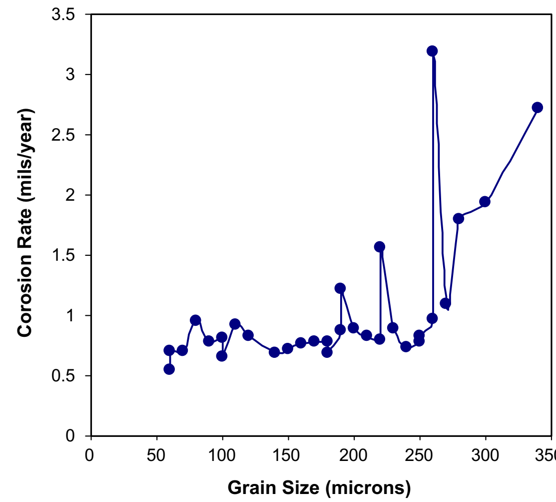

Fig. 6. Relationship between grain size and corrosion rate.

The consequence of the thermal fluctuations leads to periodic interruption in the process of solidification. As the pulse current decays, the solid liquid interface advances in towards the arc and increasingly becomes vulnerable to any disturbances in the arc form. It is also true that mechanical and thermal disturbances to the weld pool at low frequency of pulsing are expected to be less intense. At low frequencies, the vibration amplitude and temperature oscillation induced on the weld pool is reduced to greater extent resulting in reduced effect on the weld pool. Moreover, at high pulse frequency values the molten pool is agitated more resulting in grain refinement in the weld region, in turn resulting in increased corrosion resistance. Hence there exists an optimum pulse frequency at which grain refinement is optimum leading to improved corrosion resistance. Thus there exists an optimum frequency at which greatest effect is produced. In the current investigation, the frequency of 6 Hz resulted in maximum grain refinement.

From the test results obtained, it is evident that the corrosion rate tends to decrease when the pulse frequency is increased from 0 to 6 Hz. The increase in corrosion resistance is normally due to slow cooling rate in Tungsten Inert Gas (TIG) welding, which results in more refined equi-axed grains as evidenced in the microstructure exhibited in Fig. 5. Grain size was found to decrease with increase of pulse frequency and peak current up to an optimum frequency of 6 Hz and then decreased. The decrease of grain size has attributed towards increase of corrosion resistance as evidenced in Fig. 6.

4. Conclusions

The effect of pulsing current on corrosion rate of GTAW titanium alloy was studied. It was observed that effect of pulsing frequency and peak current had two regions with initially decreasing the corrosion rate and then increasing the corrosion rate irrespective of changes in base current and pulse on time. Current pulsing in GTAW has lead to relatively finer and more equi-axed grain structure in titanium welds. It has been understood that there is a value of optimum frequency at which the corrosion rate is minimum. The grain refinement due to current pulsing has resulted in increase in corrosion resistance. Of the four pulsed current parameters, peak current and pulse frequency are having predominant effect on corrosion properties.

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