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Pitting corrosion studies on Ti6Al4V alloy weldments in marine environment

V. K. Bupesh Raja[1*], K. Palanikumar [2], Arja Sri Sai[3], & Bandi Vedaraj Goud[3]
[1]School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India
[2]Sri Sai Ram Institute of Technology, Chennai, Tamil Nadu, India
[3]Department of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India
[*][E-mail: bupeshvk@gmail.com]

Titanium and its alloys are widely used owing to their high strength-to-weight ratio, good tensile strength, and resistance to corrosion. The Ti6Al4V alloy is called the workhorse among the titanium alloys owing to its wide application. Even though the Ti6Al4V alloy is immune to corrosion, improper welding conditions lead to contamination, making the weldments prone to stress corrosion cracking (SCC). These weldments are susceptible to SCC if they show sensitivity to pitting. This study examines the effect of welding conditions on the pitting corrosion behavior of 3 mm thick plates of Ti6Al4V alloy. The Ti6Al4V weldments were fabricated using fusion welding methods, namely, the gas tungsten arc welding (GTAW) and laser beam welding (LBW) techniques. The pitting corrosion studies were carried out by a potentiodynamic polarization technique, using non-deaerated 3.5% NaCl solution of pH 7, to create a marine corrosion environment. The pitting corrosion studies yielded good results as there was corrosion resistance in weldments fabricated under controlled conditions.

[**Keywords:** Ti6Al4V; Pitting corrosion; Marine; Stress cracking corrosion; Weldment]

Introduction

Titanium is widely used in a variety of applications, such as aerospace, marine, offshore, surgical implants, racer cars, armaments, and chemical processing equipment. The Ti6Al4V titanium alloy designated as ASTM B265 Grade5 is the most commonly used among the 39 grades of titanium alloys[1,4]. Ti6Al4V is considered the military grade of titanium. Titanium has good corrosion resistance due to the spontaneous formation of a passive oxide film of TiO_2 at room temperature. The oxide film is very stable, continuous, and highly adherent. The oxide film may comprise a mixture of titanium oxides, such as TiO_2, Ti_2O_3, and TiO[5]. Pitting corrosion is localized corrosion resulting in the appearance of holes on the metal surface. Even though pitting causes minimal loss of metal, pitting leads to perforation, causing loss of functionality and reliability of the equipment and components. Therefore pitting corrosion has been studied in this investigation[6].

Inspite of its good weldability, Ti6Al4V is prone to contamination by the atmospheric gases, leading to hydrogen embrittlement and poor mechanical properties. Traditionally, the gas tungsten arc welding (GTAW) technique is used to weld Ti6Al4V. Owing to high heat input for a longer duration, GTAW produces a broader heat affected zone (HAZ). In critical applications, the high-energy beam technique of laser beam welding (LBW) is preferred to GTAW since it produces a smaller HAZ[7]. In this investigation, both GTAW and LBW were studied to determine the effect of these processes on the pitting corrosion of Ti6Al4V alloy. The objective of this study is to evaluate the quality of the weld and explore the feasibility of welded titanium components in marine applications.

Materials and Welding Process

The square butt joints were autogenously fabricated from cold-rolled, annealed plates of Ti6Al4V of size 50 mm × 125 mm × 3 mm along the rolling direction. The composition of the base metal was determined using a vacuum optical emission spectrometer (SPECTROLAB, Germany) (Table 1).

The GTAW was done manually by a highly skilled welder, using Easy Weld SSR 400/600, 3 phase, 415 V ± 10%, 50 Hz AC equipment. The GTAW was done with a root gap of 1.6 mm, while LBW was done with no root gap, since any gap between the plates allows the laser beam to pass through without any welding taking place. Proper care was taken to prevent contamination, distortions, and embrittlement, by using 99.9% pure argon with top and bottom purging and suitable clamping. The frequency of the GTAW was kept constant at 6 Hz. The laser beam-welding machine used for this experiment was a transverse-flow, carbon dioxide LASER. The LBW was done by conduction method, which is used for low-power heat

Table 1 — Chemical composition (wt %) of the base metal

Al	V	C	Si	Mn	Cr	Ni	Cu	Fe	Sn	Ti
6.508	3.943	0.034	0.005	0.0048	0.014	0.0136	0.0050	0.183	0.028	89.253

Table 2 — GTAW parameters

Weld Bead	Current A	Volt V	Feed mm/minute
Root run	102	17	134
Fill up	86	16.2	188

Table 3 — LBW parameters

Current A	Voltage KV	Power KW	Feed mm/minute
25	2.12	3.5	56

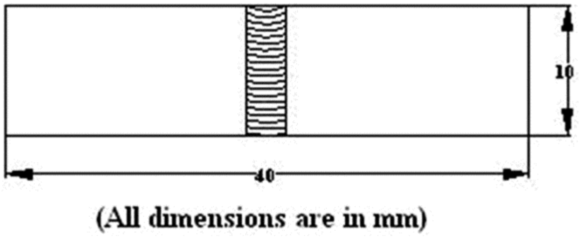

Fig. 1 — Corrosion specimen

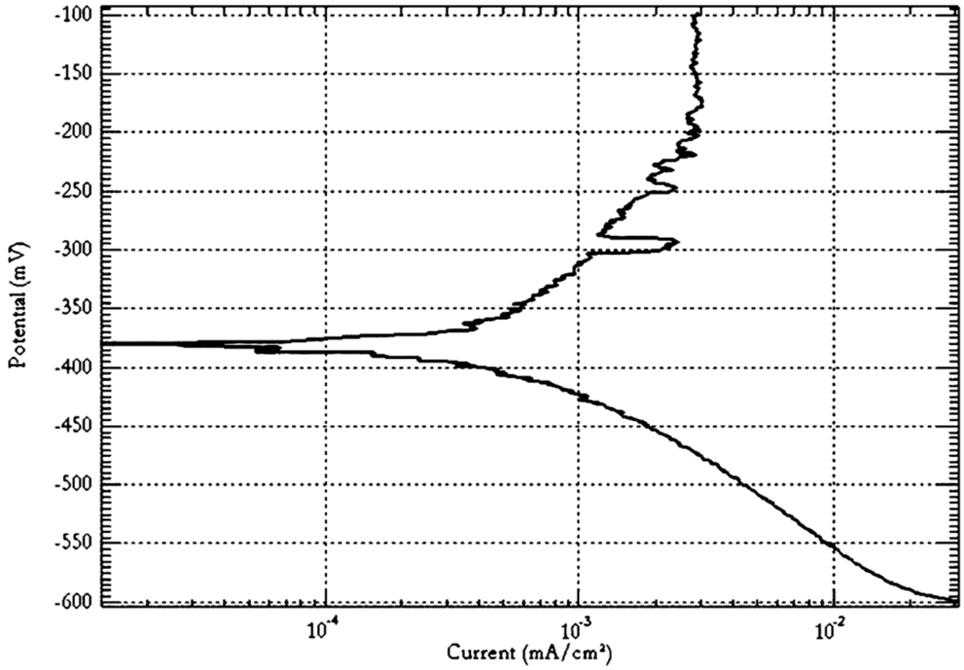

Fig. 2 — Potentiodynamic polarization curve of GTAW weldment

requirements[8,12]. The weld bead, quality of weld, and full penetration were achieved by selecting suitable welding parameters (Tables 2 and 3).

Corrosion Test

The as-welded corrosion test specimens of size 10 mm × 40 mm were polished to mirror-finish following metallographic procedures using diamond compound of 1 μm particle size. The corrosion analysis was done taking the top surface of the welded surface as the area of interest (AOI), instead of the cross-section, since the surface is exposed more to the environment[13]. In the AOI, a 4 mm diameter circular area of the weld region was exposed to the electrolyte by coating the other surfaces with acid-resistant lacquer (Fig. 1).

The potentiodynamic polarization of the GTAW and LBW weldments was done using ACM GILL AC Potentiostat, an ASTM standard cell, and personal computer. A non-deaerated 3.5% NaCl solution of pH 7 was used for conducting the polarization studies. The polarization studies yielded the potentiodynamic curves shown in Figures 2 and 3.

The pitting corrosion was detected by morphological analysis of the surface using optical microscope METAVIS 1000[9,10] (Figs 4 and 5).

Result and Discussions

The Ti6Al4V alloy possesses excellent corrosion resistance in its as-milled condition. The improper parameters and processing environment makes it prone to corrosion due to contamination. This is critical in the

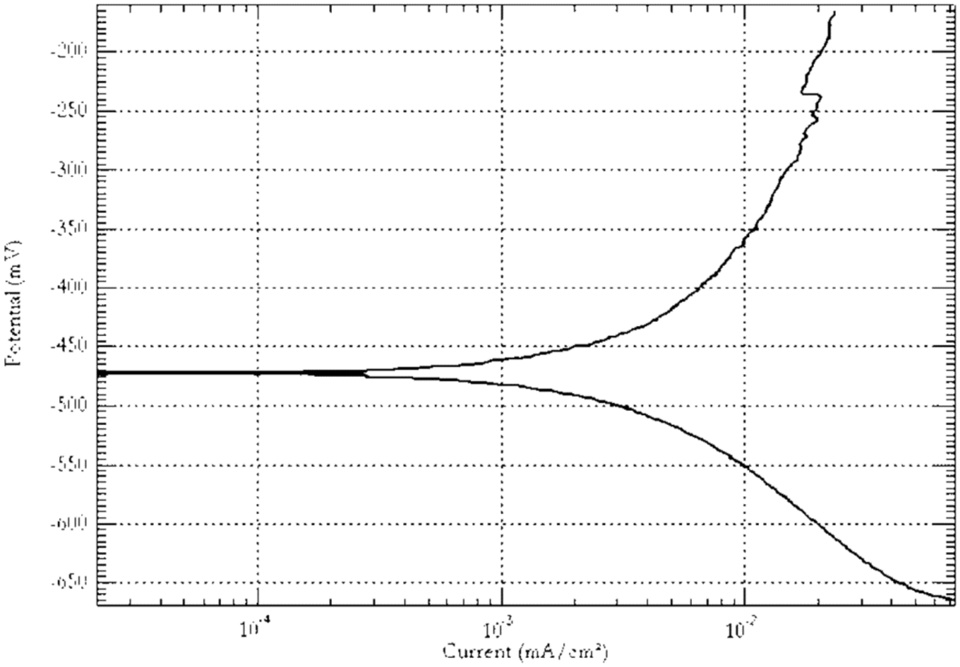

Fig. 3 — Potentiodynamic polarization curve of LBW weldment

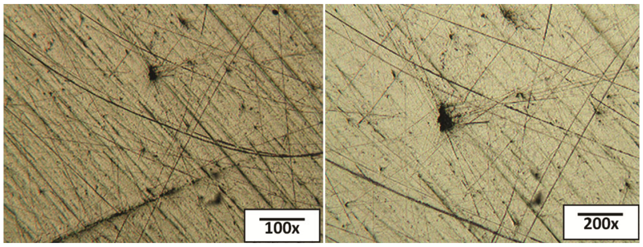

Fig. 4 — Weld surface after corrosion test of GTAW weldment

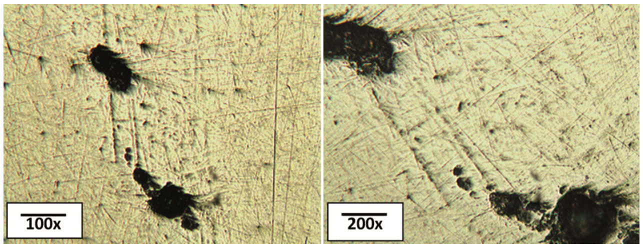

Fig. 5 — Weld surface after corrosion test of LBW weldment

case of welded structures which are exposed to harsh marine environment. The presence of dual phases (namely, the α and β-phases) in the alloy makes welding a challenge. The population of the phases and formation of new phases influence the mechanical properties and the immunity to corrosion. The heat input and the argon shielding have a critical effect on the weld quality and its service life in the marine environment. The GTAW welding, being a low-heat-intensity technique when compared with the LBW technique, has its typical signature effect on the quality of the weldment.

The formation of columnar grains and less martensite formation in a matrix of α grains, which makes the GTAW weldment, resist corrosion[11,18]. The GTAW process provides heat input in a slow manner, leading to a process-induced annealing effect and thus causing a decrease in the hardness of the Ti6Al4V alloy. In LBW, rapid heating is followed by rapid cooling. The whole matrix gets converted into α prime (martensite), with the earlier β grain boundary being retained. This causes increase in hardness and decrease in corrosion resistance[19,22]. Further, the rapid heating and cooling causes thermal stresses in the laser beam weldments, making it less resistant to corrosion. The pitting corrosion rate of the GTAW process is 0.45 mils/year and that of the LBW process is 1.66 mils/year; these values are within permissible limits. The corrosion test results indicate material degradation through corrosion on the surface of the alloy with few superficial pits caused by the formation of a protective passivation layer on the surface. Proper selection of welding parameters and effective shielding of the weld pool with ample argon gas purging helped achieve good-quality weldments in spite of the inherent virtues of the GTAW and LBW techniques, without compromising the mechanical properties and corrosion resistance of the Ti6Al4V alloy.

Conclusion

The effect of GTAW and LBW on corrosion of Ti6Al4V alloy was studied. It was observed that the corrosion rate in the GTAW process was lower than that in the LBW process. In non-deaerated 3.5% NaCl solution of pH 7, the Ti6Al4V showed pitting corrosion rate of 0.45 mils/year for GTAW and 1.66 mils/year for LBW. The grain refinement caused by the GTAW resulted in increased corrosion resistance, while the rapid heating and cooling during LBW reduced corrosion resistance. This indicates that the GTAW welding technique does not hamper the corrosion resistance of the Ti6Al4V alloy components, whereas the LBW welded components need heat treatment to improve their corrosion resistance in marine environment.

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