

Corrosion Behavior of Laser-Welded Ti6Al4V in 3.5 % Wt NaCl



P. O. Omoniyi, R. M. Mahamood, N. Arthur, S. Pityana, S. Skhosane, T. C. Jen, and E. T. Akinlabi

Abstract Titanium and its alloys, especially Ti6Al4V, have greatly revolutionized the manufacturing industry. Ti6Al4V, the workhorse of industries, has been widely used in the aerospace, automobile, and marine industry due to its outstanding corrosion resistance and good strength-to-weight ratio. This article investigates the corrosion potentials of Ti6Al4V joined using laser welding in 3.5%wt sodium chloride (NaCl) and compares it with an unwelded Ti6Al4V sheet. The samples were characterized using the Tafel curve, open-circuit potential, and scanning electron (SEM) images. Results showed that the unwelded sample exhibited higher corrosion resistance when compared to the laser-welded sample.

Keywords Corrosion · Laser welding · Microstructure · NaCl · Ti6Al4V

1 Introduction

The joining of metals, especially welding, has been used in various industries due to its strength over brazing and fasteners such as rivets, bolts, and nuts. Welding Ti6Al4V in recent decades has been perfected to an appreciable stage, with the use of laser welding, which offers a great advantage of small heat-affected zone over

P. O. Omoniyi (✉) · R. M. Mahamood · T. C. Jen · E. T. Akinlabi
Mechanical Engineering Science Department, University of Johannesburg, Johannesburg 2092, South Africa
e-mail: omoniyi.po@unilorin.edu.ng

P. O. Omoniyi
Mechanical Engineering Department, University of Ilorin, PMB 1515, Ilorin, Nigeria

R. M. Mahamood
Department of Materials and Metallurgical Engineering, University of Ilorin, PMB 1515, Ilorin, Nigeria

N. Arthur · S. Pityana · S. Skhosane
CSIR, National Laser Center, P. O. Box 395, Pretoria, South Africa

E. T. Akinlabi
Pan Africa University for Life and Earth Sciences Institute, Ibadan 200005, Nigeria

other fusion welding such as gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) [1, 2]. However, due to the heat required in joining these metals, changes in microstructure and atmospheric contaminations are bound to occur [3]. The change in microstructure at the weld zone (heat-affected zone and fusion zone) has been reported to affect the corrosion resistance of Ti6Al4V [4]. The acicular α' and martensitic microstructure have been reported as the primary source of pitting corrosion in Ti6Al4V [5]. Even though Ti6Al4V is known to have high corrosion resistance, due to the passive film of titanium dioxide (TiO_2) formed on its surface, the breakage of the film could be a result of environmental conditions [6]. Works of literature have reported the dissolution of the passive film formed on Ti6Al4V in halide ions. Chloride ion (Cl^-) has been reported to deplete the oxide layer and exposes Ti6Al4V to aggressive pitting [3].

This research aims to study the effect of sodium chloride (NaCl) solution on the passive film formed on laser-welded Ti6Al4V alloy. It further investigates the microstructure of the laser-welded Ti6Al4V. This research will give a good guide on numerical studies and simulation of corrosion of Ti6Al4V in the marine environment.

2 Methods

2.1 Laser Welding of Ti6Al4V

Titanium alloy (Ti6Al4V) sheets with a chemical composition consisting of 6.1% aluminum, 4% vanadium, 0.15% iron, and the remaining titanium, were joined using a 3 kW CW YLS-2000-TR ytterbium laser system. Each Ti6Al4V sheet measured 100 mm $\times$ 60 mm $\times$ 1 mm and was joined in butt configuration. Prior to welding, the faying surfaces were cleaned with acetone to remove contaminations. Argon gas with a 15 L min^{-1} flow rate was used as a shield to protect the welds from atmospheric contamination. Laser power of 2.6 kW and welding speed of 2.6 m min^{-1} were used in joining the Ti6Al4V sheets. The choice of parameters was made as a result of an ongoing study [1], where the welding parameters used exhibited the highest tensile strength. Optical images of the microstructure of the welded metals were captured using Olympus DP 25 microscope.

2.2 Corrosion Studies

Samples measuring 20 mm $\times$ 10 mm $\times$ 1 mm were cut out of the Ti6Al4V sheets for corrosion studies. Each sample was mounted on a cold setting epoxy resin with a copper wire soldered to an end of the metal sample. The samples were grinded using SiC papers ranging from #320 to #4000, cleaned with acetone and rinsed in distilled water. The experimental setup consisted of the sample as the working

electrode, Ag/AgCl as the reference electrode, and the counter electrode was platinum rods. To obtain a stable open-circuit potential, a 200 mm² surface area was exposed to the sodium chloride (NaCl) solution for two hours at ambient temperature (open-circuit potential, OCP). The corrosion potentials were measured using a DY2300 model potentiostat with DY2300EN software. The potentiodynamic polarization experiment used dynamic potential values ranging from -0.25 to $+0.25$ V, and the potentiodynamic scan rate was 1.0 mV/s. Corrosion current (I_{corr} A) and corrosion potential are also measured (E_{corr} V).

3 Results and Discussion

3.1 Microstructure of Laser-Welded Samples

The microstructure of the laser-welded sample is characterized into three zones, namely: heat-affected zone (HAZ), base metal (BM), and fusion zone (FZ) Fig. 1. The BM comprises the white alpha (α) and black beta (β) phases [2, 7, 8]. Furthermore, the HAZ is categorized into far HAZ and near HAZ. The far HAZ is made of the blocky α microstructure and some untransformed β phases, while the near HAZ is close to the FZ [9]. The near HAZ contains acicular α' microstructure resulting from the zone attaining temperature above the β transus temperature of 995 °C then cooling rapidly in the air [10]. The FZ contains α martensitic microstructure resulting from the zone attaining the liquidus temperature then cooling above the critical cooling temperature rate of 410 °Cs⁻¹ [1, 11–13].

3.2 Corrosion Analyses

The scanning electron microscopy (SEM) observation of the unwelded sample Fig. 2 and that of the welded sample Fig. 3 after exposure to 3.5%wt sodium chloride (NaCl) solution shows no corrosion attack on the surface except the carbon particles picked up during grinding operation using the silicon carbide (SiC) papers, as shown in the energy dispersive spectroscopy (EDS) chart. The lack of corrosion attack could be attributed to the passive film formed by the metal on its surface. A similar occurrence was also observed by [5].

Tafel curve plot depicted the rate of corrosion in the welded Ti6Al4V is higher than the unwelded samples Fig. 4. The unwelded sample exhibiting a lower corrosion rate could be attributed to the microstructure of the material. The equiaxed α and β phases show a higher volume fraction of β in it than the welded zone. Works of literature attributed the β phase to be the significant cause of an enhanced corrosion resistance in Ti6Al4V alloy [14]. The corrosion performance of the unwelded sample could further be ascribed to the passive film formed on the material's surface, thereby resulting

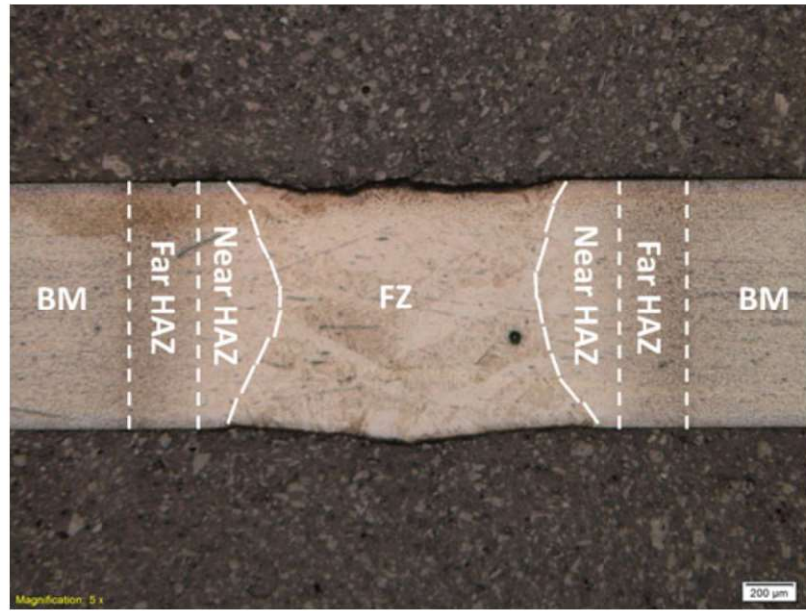


Fig. 1 Microstructure of laser-welded Ti6Al4V

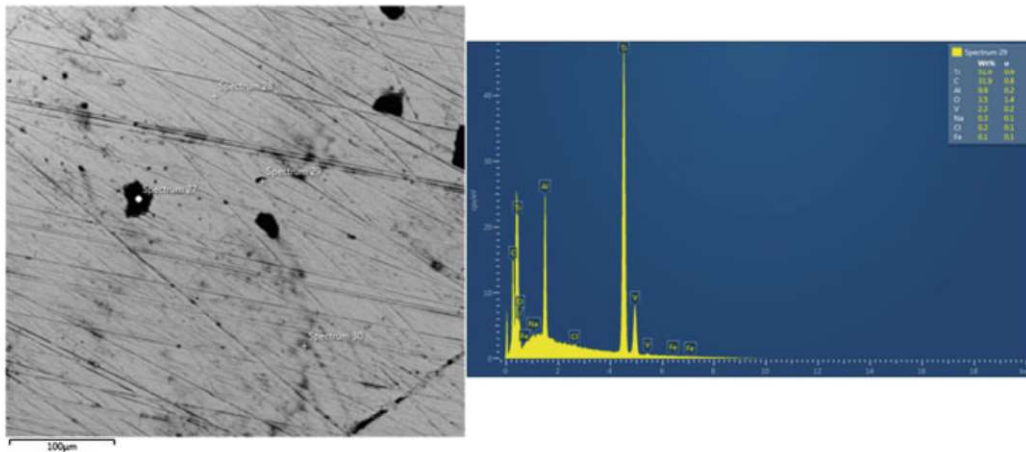


Fig. 2 Unwelded Ti6Al4V surface after corrosion test

in a higher corrosion current (i_{corr}) value of $499 \mu\text{A cm}^{-2}$ than the welded sample $152 \mu\text{A cm}^{-2}$. The corrosion potential (E_{corr}) value for the welded and unwelded are -0.471 V and 0.006 V , respectively. Generally, the corrosion rates for both samples are within the perfectly stable range of $<10^{-3} \text{ mm year}^{-1}$ [14, 15].

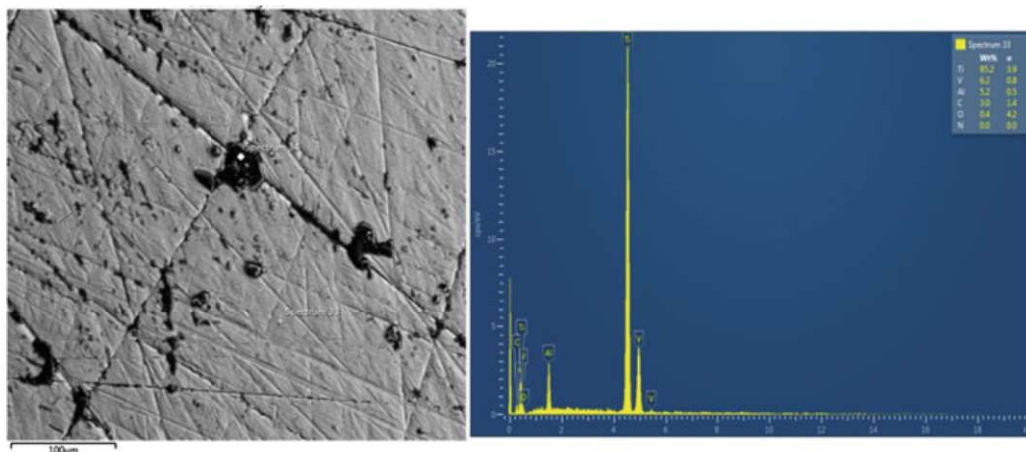
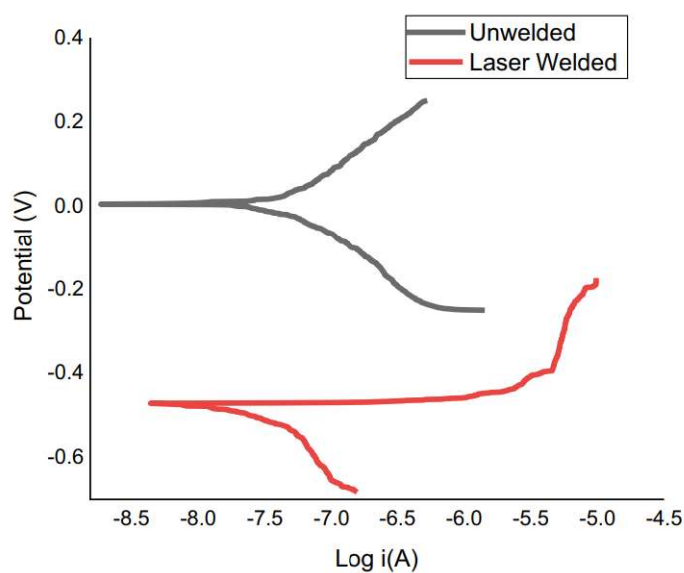


Fig. 3 Laser-welded Ti6Al4V surface after corrosion test

Fig. 4 Tafel curves of welded and unwelded samples



4 Conclusions

Laser welding and corrosion studies have been carried out on Ti6Al4V submerged in sodium chloride (NaCl) solution. The following conclusions are drawn from the research.

1. The welded sample's fusion zone comprises a martensitic microstructure, and the heat-affected zone contains an acicular α' microstructure.
2. The unwelded sample had a higher resistance to corrosion than the welded sample.
3. All samples performed perfectly stable in 3.5%wt NaCl, i.e., the corrosion rate is less than $10^{-3} \text{ mm year}^{-1}$.

References

1. Casalino G, Mortello M, Campanelli SL (2015) Ytterbium fiber laser welding of Ti6Al4V alloy. *J Manuf Process* 20:250–256
2. Ferdinandov NV, Gospodinov DD, Ilieva MD, Radev RH (2018) Structure and pitting corrosion of Ti-6Al-4V alloy and Ti-6Al-4V welds. In: *Proceedings of the 7th international conference on advanced materials and systems*, pp 325–330
3. Gao XL, Zhang LJ, Liu J et al (2014) Effects of weld cross-section profiles and microstructure on properties of pulsed Nd:YAG laser welding of Ti6Al4V sheet. *Int J Adv Manuf Technol* 72:895–903
4. Kabir ASH, Cao X, Medraj M et al (2010) Effect of welding speed and defocusing distance on the quality of laser welded Ti-6Al-4V. *Mater Sci Technol* 4:2787–2797
5. Liu J, Gao XL, Zhang LJ et al (2014) A study of fatigue damage evolution on pulsed Nd: YAG Ti6Al4V laser welded joints. *Eng Fract Mech* 117:84–93
6. Omoniyi PO, Akinlabi ET, Mahamood RM (2021) Heat treatments of Ti6Al4V alloys for industrial applications : an overview. In: *4th international conference on engineering for sustainable world*. <https://doi.org/10.1088/1757-899X/1107/1/012094>
7. Omoniyi PO, Akinlabi ET, Mahamood RM et al (2021) Corrosion resistance of heat treated Ti6Al4V in NaCl. *Chem Data Collect*. <https://doi.org/10.1016/j.cdc.2021.100780>
8. Omoniyi PO, Mahamood RM, Akinlabi ET (2021) Impact of process parameters of laser welding on the mechanical properties of Ti6Al4V: a review. *J Chem Technol Metall* 56:1074–1081
9. Omoniyi PO, Mahamood RM, Arthur N et al (2021) Investigation of the mechanical and microstructural properties of TIG welded Ti6Al4V alloy. *Adv Mater Sci Eng Sel Artic ICMMP* 2020:111–118
10. Omoniyi P, Mahamood R, Arthur N et al (2021) Laser butt welding of thin Ti6Al4V sheets: effects of welding parameters. *J Compos Sci* 5:1–9
11. Raja VKB, Palanikumar K, Sai AS et al (2019) Pitting corrosion studies on Ti6Al4V alloy weldments in marine environment. *Indian J Geo-Marine Sci* 48:1179–1182
12. Shamir M, Junaid M, Nawaz F et al (2019) A comparative study of electrochemical corrosion behavior in laser and TIG welded Ti—5Al—2. 5Sn alloy. *J Mater Res Technol* 8:87–98
13. Squillace A, Prisco U, Ciliberto S et al (2012) Effect of welding parameters on morphology and mechanical properties of Ti-6Al-4V laser beam welded butt joints. *J Mater Process Technol* 212:427–436
14. Yang J, Yang H, Yu H et al (2017) Corrosion Behavior of additive manufactured Ti-6Al-4V alloy in NaCl solution. *Metall Mater Trans A Phys Metall Mater Sci* 48:3583–3593
15. Zhang Y, Feng L, Zhang T et al (2021) Heat treatment of additively manufactured Ti-6Al-4V alloy: microstructure and electrochemical properties. *J Alloys Compd* 888:161602