

# Microstructure and Corrosion Behaviour Ti6Al4V + W Composites in 3.5 wt% NaCl Solution of Laser Metal Deposition

N. Ndou

**Abstract**— The polarisation current density, the open circuit potential (OPC), and the corrosion rate of the Ti6Al4V + W coating prepared using a 3.5 wt% NaCl solution were analysed. The corrosion tests performed on a coated sample of Ti6Al4V + W revealed excellent corrosion resistance that was kinetic active and steady in a NaCl solution. Surface integrity of Ti6Al4V was improved after the inclusion of W particles. Laser deposition process was used with different laser power of 800 W, 900 W, 1000 W, 1200 W and 1400 W with a constant scanning of 0.5m/min. The best corrosion resistance was observed at a laser power of 1000 W with a scanning speed of 0.5m/min. The highest hardness was also observed at a laser power of 1000 W. The scanning electron microscopy (SEM) was used to provide a high amplification image and high magnification image of the specimen. SEM was also used to analyse the microstructures of the coated sample.

The microstructures of Ti6Al4V+W displayed the white core-rim structure and the black core-rim structure. With the addition of W, the inner rim increased.

**Index Terms**— Heat affected zone, Laser metal deposition

## I. INTRODUCTION

Titanium and other alloy materials are important for enhancement in the marine, energy, motor vehicle, automobile and aerospace industries [1]. Most of the material are exposed to corrosion tests depending on the condition and the nature of the material itself [2]. The presence of Ti6Al4V metallic phases has increased, thereby improving the corrosion resistance.

The study of Ti6Al4V powder coating has turned out to be an exciting topic due to its many applications in different fields. The corrosion abilities of the alloyed laser specimens reduce as the Ti6Al4V content increases. The enhancement in the corrosion resistance of Ti6Al4V was attributed to the existence of Ti6Al4V in the intermetallic and metallic

Manuscript received July 16, 2019; revised July 24, 2019. This work was supported in part by the Rental Pool Programme of National Laser Center, Council of Scientific and Industrial Research (CSIR), Pretoria, South Africa.

N. Ndou is a Doctor with the Department of Mechanical and Industrial Engineering, University of South Africa, Florida 1710, South Africa, (UNISA Staff Member) [nndou@unisa.ac.za](mailto:nndou@unisa.ac.za)

stages for shaping the defensive oxide [3]. The corrosion application in all materials is regarded as the most important because it influences the lifespan of the material in a demanding environment.

The laser deposition process method is viewed as the appropriate method to improve surface modification because it is easy to control, and the treatment focuses on the specific area [4]. Laser surface modification has been used to restore the surface of the material by re-melting the surface and this process has been viewed as the best method to improve surface modification [5].

The corrosion resistance for titanium Ti6Al4V was characterised by 3.5wt% NaCl solution. This study objective is to determine the impact of laser metal deposition process on the corrosion resistance of Ti6Al4V+W in 3.5wt% NaCl solution.

## II. EXPERIMENTAL METHODS

### A. Samples preparation and equipment

All substrates were cleaned with a sandblast to remove all unwanted material on a substrate. The substrate was also cleaned with acetone to encourage better bonding between substrate and deposited material. Two separated feeders were used to set up the powders. The feeders were loaded with two powders – Ti6Al4V and W powders. The powders were set up by the predefined ratio on the experiment setup. It is better to use separated powder feeders rather than pre-mixed powders because pre-blended powders are not uniform in density.

A Ti6Al4V solid plate was used as the substrate, with a size of 107 x 107 x 8 mm<sup>3</sup>. A laser metal deposition process was used, with the laser power of 0.8 kW, 0.9 kW, 1.2 kW, 1 kW and 1.4 kW and a constant laser scanning speed of 0.5 m/min. A 2 mm beam diameter was used throughout the experimental procedure with a focal point of 15 mm under the substrate surface. The metal brush was used to clean unwanted melted sparks forming during the deposition process. All specimens were carefully ground, polished and etched according to the ASTM standard [6].

The coated samples were etched with water, hydrofluoric acid and nitric acid to reveal microstructure on the deposited

coated sample using Kroll's Reagent. Figure 1 is a schematic view of the laser cladding method.

The deposited sample was cut by using a special grinding disc to reveal the cross section of the deposited sample. All coated samples were mounted using PolyFast resin. After the mounting of the coated sample, all samples were polished to remove unwanted impurities on the surface.

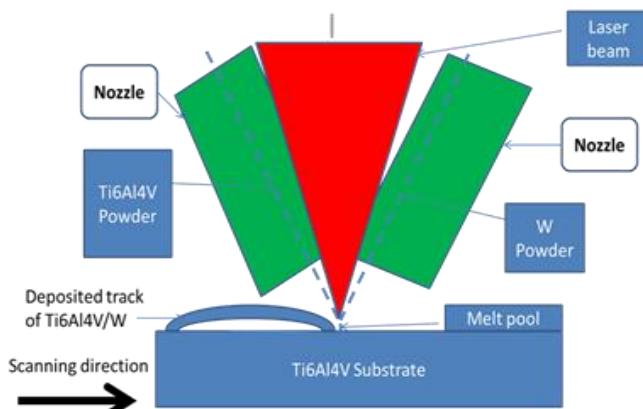


Figure 1: Schematic diagram demonstration of the laser metal deposition process

The laser metal deposition process was used to produce a coated sample. Table 1 shows the powder flow rate of the Ti6Al4V+W and the gas flow rate. The laser power was varied between 0.8 kW and 1.4 kW. The scanning speed remained constant throughout the experiment.

Table I: Experimental Matrix

Specimen names	Power (W)	Scan speed (m/min)	Powder rate (rpm)		Gas rate	
			Ti	W	Ti	W
N1	800	0.5	9.5	0.5	1.5	3
N2	900	0.5	9.5	0.5	1.5	3
N3	100	0.5	9.5	0.5	1.5	3
N4	1100	0.5	9.5	0.5	1.5	3
N5	1200	0.5	9.5	0.5	1.5	3

### B. Microstructure

After polishing, all coated samples were etched for 10–15 s using Kroll's Reagent. The preparation was set up with 100 ml H<sub>2</sub>O, 2–3 ml hydrofluoric acid and 4–6 ml nitric acid. The coated samples were carefully polished, cleaned with acetone, washed with clean water and dried off to reveal the microstructure. The samples were prepared according to E3-11 ASTM standards [6]. The samples were polish using MD CHEM. The microstructure was analysed in detail with a BX51M Olympus microscope. Further analyses for microstructure were characterised using JOEL scanning electron microscopy (SEM) with X-ray energy-dispersive spectroscopy (EDS). SEM was utilized to give high resolution and high amplification pictures of the specimen

### C. Hardness

The indentation was performed on the etched sample by using the microhardness tester, which was available at the University of Johannesburg, Kingsway Campus, Johannesburg, South Africa. The dwelling time of 12 s and the indentation load of 500 g was used. The spacing between indentation applied was 100 µm. The hardness test was conducted according to the E384-11el ASTM standard [7].

### D. Corrosion test

The corrosion test was performed at the University of Johannesburg (UJ) to determine the corrosion measurement. All the coated samples were run for 3 600 s in an Open Circuit Potential (OCP). The corrosion test was conducted by utilising the potentiostat equipment with GPES software. An estimating glass tube was set up with 3.5wt% NaCl solution and the reference electrode (RE) tube was stacked with potassium chloride. The RE and the electrode were put into the breaker cylinder to complete the circuit. The coated sample were put into the breaker cylinder and the reference electrode were placed in a focal point to detect the coating on the sample. The conductive wire was placed on the coated sample and was covered with aluminium tape. The conductive wire was placed inside the mould and blended with epoxy resin. The corrosion measurement of Ti6Al4V + W coatings were evaluated at a room temperature using 3.5wt% NaCl solution. The corrosion test was analysed by using the standard work according to [8].

## III. RESULTS

### A. Microstructure

Ti6Al4V alloy has good corrosion resistance in different environments. The impact of W particles on the erosion and microstructural conduct of Ti6Al4V in 3.5 wt% NaCl solution was considered. Figure 2 represents the surface morphology of the Ti6Al4V+W. Figure 2 also reveals the presence of W content with white cores.

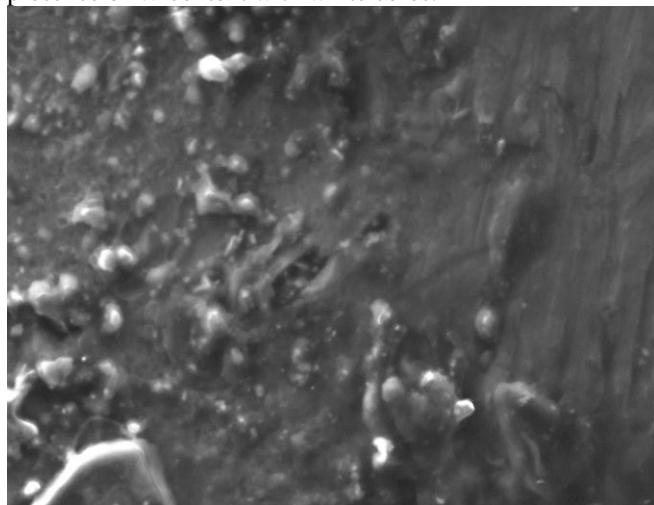


Figure 2: Surface morphology of the Ti6Al4V+W in 3.5 wt% NaCl solutions

As shown in Figure 2, there is a sign of pitting corrosion on the outside of the Ti6Al4V. The pitting corrosion indicates that the passive film in the region is weak. The addition of W particles in the Ti6Al4V gave a shield against the pitting corrosion. Figure 2 also shows the white core which is W content and the black core grey rim structures which are Ti6Al4V. The black cores are unmelted Ti6Al4V particles.

### B. Hardness

The hardness was conducted from the top zone of the deposited material up until the substrate material. This was done following the [7] standard. The increase in hardness was found in all coated material deposited with the laser metal deposition process compared to the substrate. Figure 3 shows that the laser power deposited from 800 W to 1 000 W increased in hardness while laser power deposited at 1 200 W had a drop-in hardness. Laser power deposited at 1 000 W shows the highest value of 719 Hv. Ti6Al4V + W shows the highest hardness value; this may be attributed to the spreading of Ti6Al4V particles and the W particles. The hardness of Ti6Al4V + W was enhanced compared to the substrate material and this was also seen by [9].

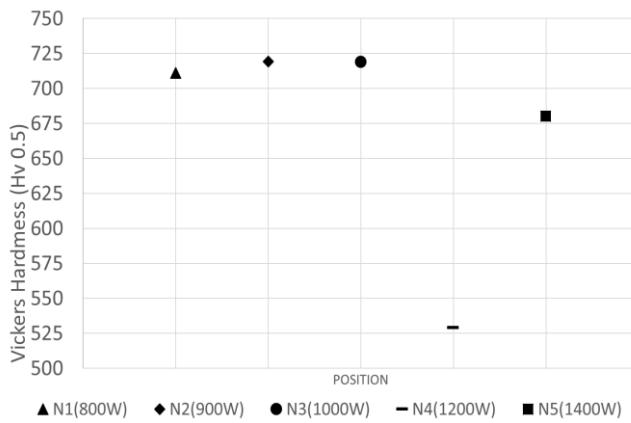


Figure 3: Micro-hardness distributions in the composite coatings

### C. Corrosion

Corrosion tests were performed on the coated sample of Ti6Al4V+W particles, and all the coated samples were ran in Open Circuit Potential (OCP) for 3 600 s with a scan rate of 2 m V/s. The corrosion resistance of Ti6Al4V + W was performed and assessed at room temperature, using a 3.5 wt% NaCl solution. Figure 4, specimen (a) to specimen (e) display the OCP potential in 3.5 wt% NaCl solutions for Ti6Al4V+W coatings deposited at variable laser powers of 0.8 kW, 0.9 kW, 1 kW, 1.2 kW and 1.4 kW and a constant scanning speed of 0.5m/min.

The OCP deposited with a coated specimen of 0.8 kW laser power and the scanning speed of 0.5m/min are shown in Figure 4, specimen (a); and this demonstrates a sharp increase in the erosion rate from -0.076 V to -0.0342 V at 1059 seconds. It likewise demonstrates a reduction in corrosion at -0.0361, until the end at 3600 seconds. The coated specimen displays a rise in the erosion rate and the film growth on the surface of the electrolyte. Figure 4,

specimen (b) shows a sample of a laser power of 900W and scanning speed of 0.5m/min with a rise in the corrosion potential from -0.142 V to -0.1222 V at 725 seconds; and it displays a sharp reduction from -0.151 V to -0.238 V at 810 seconds.

Sample b also shows a rise – from -0.250 V to 0.100 V at 2 839 seconds; and it drops again from -0.09 V to -0.20 V at 3 100 seconds. Figure 4, specimen (c) deposited at a laser speed of 1 000 W, and the scanning speed of 0.5m/min shows the open-circuit potential that is between -0.129 and 0.111 V up until the finish of 3 600 seconds. The coated specimen at a laser power of 1 200 W and the scanning speed of 0.5m/min demonstrated an increase in erosion rate from -0.99 V to -0.0850; however, it kept a decrease from -0.1 to -0.109 V; while it displayed a sharp decrease at -0.1140 until the end at 3600 seconds.

Figure 4, specimen(e) displays a sharp rise in the erosion rate from -0.4080 V to 0.1581 at 1 340 seconds; however, it falls once more from -0.20 V to -0.49 V at 1 538 seconds. The fall of the cathodic reading can be identified with the oxide formed on the highest point of the surface. Figure 4 illustrates the varieties in the OCP for the deposition of coated specimen at the different laser powers and the constant scanning speed of 0.5m/min.

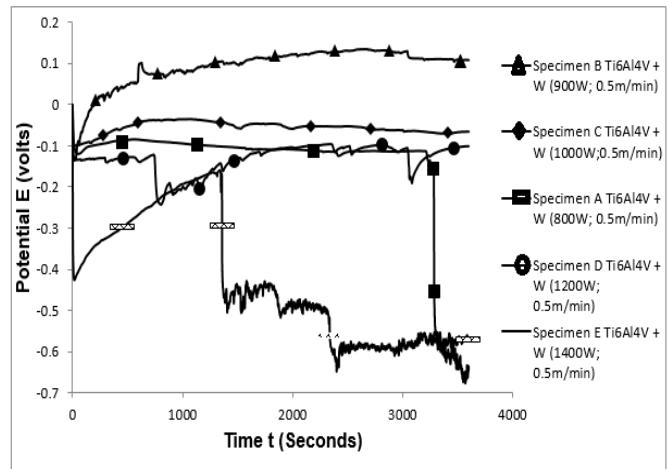


Figure 4: The variation in OCP as a function of time for Ti6Al4V/W

The highest corrosion resistance was recorded at a laser power of 1 000 W and a scanning speed of 0.5m/min. The second highest corrosion resistance was recorded at specimens (a) and (b) when compared with the other remaining samples. Specimen (c) displays an oxidation resistance. It can be seen that W shows a good corrosion resistance in the nitric acid solution. This relates well with the concept that W inclusion rises the corrosion resistance. This was also revealed by [10] – that the including of W rises the corrosion resistance; and it additionally rises its substance on the surface.

## IV. CONCLUSION

Ti6Al4V + W shows excellent corrosion resistance when compared to uncoated Ti6Al4V. The inclusion of 5 weight per cent of W content improved the surface integrity of the Ti6Al4V and it also provided good protection against corrosion attacks. The corrosion resistance test discloses

that titanium alloy shows outstanding corrosion resistance due to its passivation. Ti6Al4V +W coating is thermodynamically steady in NaCl solution.

#### ACKNOWLEDGMENT

The authors would like to thank all student assistants (laboratory technicians) at the Department of Metallurgy at Tshwane University of Technology (TUT) for assisting with equipment and setup of the equipment.

#### REFERENCES

- [1] C. LEYENS, and M. PETERS, Titanium and titanium alloys. Wiley Online Library, 2003
- [2] S. A. Al-Fozan, and A. U. Malik, Effect of seawater level on corrosion behavior of different alloys, Desalination 228 (2008) 61–67.
- [3] P. K. Wong, C. T. Kwok, H. C Man and F. T. Cheng, Corrosion Behavior of Laser-alloyed Copper with Titanium fabricated by high power
- [4] J. Ciganovic, J Stasic, B. Gakovic, M. Momcilovic, D. Milovanovic, M.Bokorov and M. Trtica, Surface modification of the titanium implant using TEA CO<sub>2</sub> laser pulses in controllable gas atmospheres—Comparative study. Applied Surface Science, 258(7), pp. 2741–2748,2012
- [5] J. Sampedro, I. Pérez, B. Carcel, J.A. Ramos, and V. Amigó, Laser cladding of TiC for better titanium components. Physics Procedia, 12, pp. 313–322, 2011
- [6] A. Standard, E3-11: Standard Guide for Preparation of Metallographic Specimens, ASTM International., West Conshohocken, PA, 2012
- [7] A. Standard, E384-11E1, —Standard test method for Knoop and Vickers hardness of materials, || in ASTM International, West Conshohocken, PA, 2007, DOI: 10.1520/E0384-11E01.
- [8] Asm handbook 2005. Corrosion: Materials. American Society for Metals International, Metals Park, OH. ASM.
- [9] O. N. Çelik, Microstructure and wear properties of WC particle reinforced composite coating on Ti6Al4V alloy produced by the plasma transferred arc method. Applied Surface Science, 274, 334–340.
- [10] C. Yi, H. Fan, J. Xiong, Z. Guo, G. Dong, W. Wan & H. Chen, Effect of WC content on the microstructures and corrosion behavior of Ti (C, N)-based cermets. Ceramics International, 39, 503–509,2013
- [11] M. T. Tlotleng, Laser-assisted deposition of titanium and hydroxyapatite biocomposites. University of Johannesburg,2013