

Characterising the Effect of Laser Metal deposited Ti6Al4V/Cu Composites in Simulated Body Fluid for Biomedical Application

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Abstract

Ti6Al4V alloy has been known to have very excellent corrosion resistance due to the oxide layer formed on its surface. Due to this property, the alloy is found applicable for biomedical implants. Copper shows an excellent antimicrobial property and has been found to stabilize the immune system. In this study, laser metal deposition of Ti6Al4V powder and Cu powder on Ti6Al4V substrates were conducted by varying the laser power between 600 W and 1800 W while the scanning speed, the powder flow rate and the gas flow rate were kept constant. The surface behaviour and the morphologies of the composites were evaluated under the microscope and the SEM after soaking for 4 hours, 5 days and 2 weeks respectively. The simulated body fluid (hank's solution) was maintained at normal body temperature of about $37\pm 1^\circ\text{C}$. The surfaces showed fracture topography with porous bone-like structures and some trivial pitting were observed.

Keywords: hank's solution; laser metal deposition; surface morphologies; SEM; Ti6Al4V/Cu composites

1. Introduction

Titanium and its alloy have been used for bio-implants due to its biocompatibility properties and according to "Titanium biocompatibility", Wikipedia, (accessed 2014), they also have the ability to resist the body fluid

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attack and become dominantly attached to the body of human. The biocompatibility and mechanical properties can be greatly affected by the corrosion of metal implants. Bidhendi and Pouranvari, 2011 reported that it is expected for any material that will be used for implants should have a good resistance to pitting and crevice corrosion in the body fluid. Gonzalez and Mirza-Rosca, 1999 revealed that due to the metal ion release in some metals, corrosion is the first priority to be considered before the insertion into the body. In the Science of Loren Pickart for the discovery of copper, (accessed 2013), the risk of copper deficiency in the body of human is much higher than the excess of copper content in the body, and it stimulates a warm flow of healing energy. The insufficiency of copper can contribute to a host of health crises such as cardiovascular disease, cancer, depression, brain malfunction and obesity. To a tolerable and allowable upper limit, the World Health Organization has recommended the intake of 10 mg/day of copper. Zhang et al., 2013 revealed that the risk of implant degradation was minimized during the modification of the surface of Ti6Al4V to augment bone ingrowths and intensify bone formation to create firm osseointegration between the host bone and the implant. Aoki et al., 2004 revealed that the addition of 1% Cu alloy to Ti6Al4V demonstrated elongation which is similar to Ti6Al4V alloys and resulted into ductile fractures. The addition of Cu has also increased the bulk hardness of the alloying composites.

The majority of these studies are preliminary studies in this field of research. However, there is a paucity of information on detailed characterization of laser metal deposition (LMD) of Ti6Al4V/Cu on Ti6Al4V substrate tailored for biomedical implants.

In this research work, 1 % of Copper (Cu) was deposited with 99 % of Ti6Al4V powders through the laser metal deposition process to enhance the functionability and modification of Ti6Al4V for bio medical application.

2. Experimental procedure

2.1. LASER METAL DEPOSITION

A 2 kW Ytterbium laser system equipment (YLS-2000-TR) was used for the experiment and connected to a Kuka robotic system that does the main work. A three way nozzle is attached to its end which allows the passage of powders and laser beam on the substrate. The two powders used in the deposition process are Ti6Al4V and Cu powders with the particle sizes varied between 150 and 200 μm . A grit blasted Ti6Al4V substrate with a dimension of 102 X 102 X 7.45 mm^3 was used. The operation was shielded by an Argon gas to prevent the contamination of oxygen on the deposited composite. The deposition was achieved with a beam diameter of 4 mm and the standoff distance of 12 mm between the nozzle tip and the substrate. The process parameters used in this present studies as depicted in Table 1 are the same to the work conducted by Erinoshio et al., 2014 on the effect of laser power during LMD process.

Table 1. Experiment matrix

Sample Name	Laser Power (W)	Scanning Speed (m/s)	Powder Flow Rate (rpm)		Gas Flow Rate (l/min)	
			Ti6Al4V	Cu	Ti6Al4V	Cu
A1	600	0.005	9.9	0.1	3	1.5
A2	900	0.005	9.9	0.1	3	1.5
A3	1200	0.005	9.9	0.1	3	1.5
A4	1500	0.005	9.9	0.1	3	1.5
A5	1800	0.005	9.9	0.1	3	1.5

2.2. HANK'S SOLUTION

The Hank's solution is an artificial body fluid used for simulating the artificial metal in place of bone with the body. The solution was deaerated and kept at 37 ± 1 °C throughout the simulation process as reported by Bidhendi and Pouranvari, 2011. The cut samples were immersed in a beaker containing the Hank's solution. The deposits were allowed to be covered by the solution in the beaker and covered with a lid. A water bath was prepared and maintained at 37 ± 1 °C. The beaker was placed in the water bath and observed. The experiment was observed for first 4 hours, 5 days and 2 Weeks.

2.3. OPTICAL MORPHOLOGICAL CHARACTERIZATION

Fig 1(a) and (b) show the SEM morphologies of Ti6Al4V and Cu powders. Both the Ti6Al4V and Cu powders show spherical morphologies. The Ti6Al4V powders were observed to have similar shapes and sizes. Smaller particles of $45\ \mu\text{m}$ to $55\ \mu\text{m}$ were found to agglomerate to the bigger particles whilst the Cu powders exhibit similar shapes but different particle sizes.

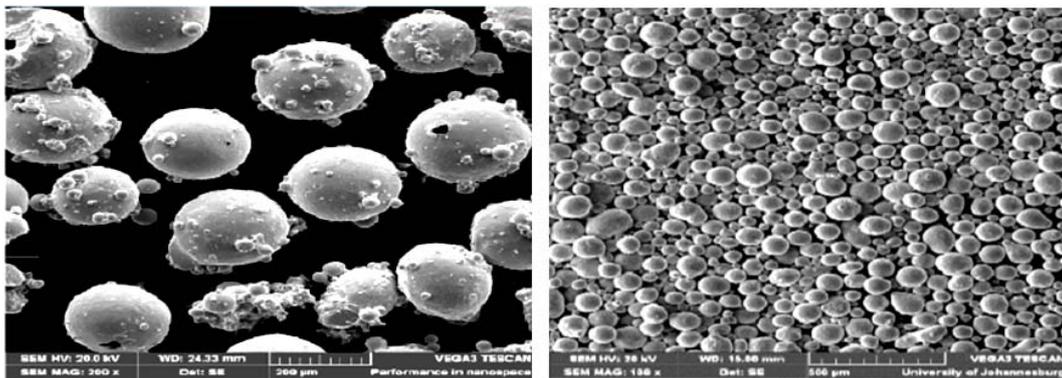


Fig. 1. (a) The SEM morphology of Ti6Al4V powder; (b) The SEM morphology of Cu powder

The surface morphology was observed on the BX51M Olympus microscope at low and high magnifications before simulated body fluid immersion, after 4 hours and 5 days of immersion.

Fig 2(a) shows the surface morphology of the Ti6Al4V/Cu composite before the immersion into the Hank's solution. Fig 2(b) and (c) show the surface of Ti6Al4V/Cu composite after the immersion for 4 hours and 5 days respectively.

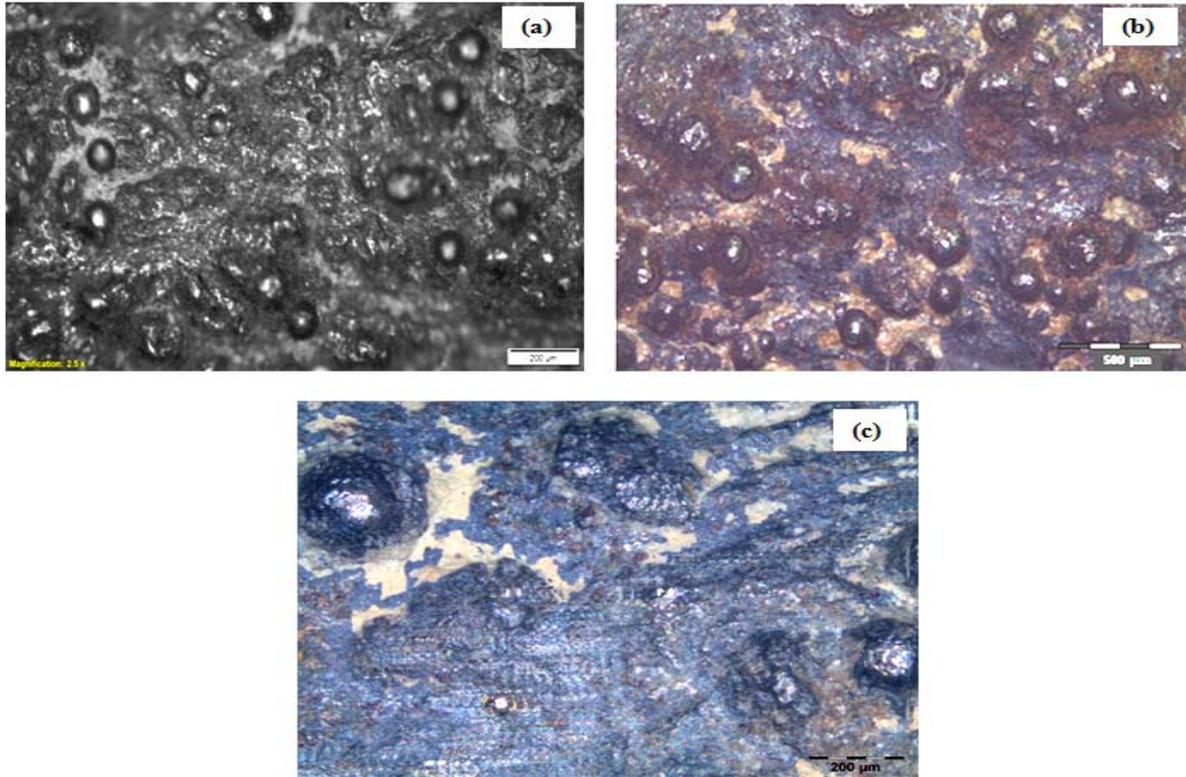


Fig. 2. Surface morphology of the Ti6Al4V/Cu composite (a) Before hank's solution immersion; (b) After 4 hours hank's solution immersion; (c) After 5 days hank's solution immersion

Fig 2(a) shows some un-melted powder particle and the roughness of the surface can contribute to its functionability for biomedical application. Fig 2(b) and (c) also showed some undissolved particles. It was observed that slight corrosion takes place on the surface. The observation on the surface was not visible to check for pores and the corroded layers and the in-depth micrograph with the optical microscope.

2.4. SEM AND EDS ANALYSIS

The Scanning Electron Microscopy (SEM) analyses were conducted using the TESCAN instrument with Vega TC software to run the analysis. The analysis was done on the surface of the deposited composite. The machine was equipped with X-MAX instrument, an Electron Dispersive Spectroscopy (EDS) using INCA-point ID software to check the atomic and weight percent of the element present in the material.

Figs 3(a) and (b) show the SEM micrograph and the EDX analysis of the Ti6Al4V/Cu composite surfaces of samples A2 and A3 after 2 weeks immersion in the Hank's solution.

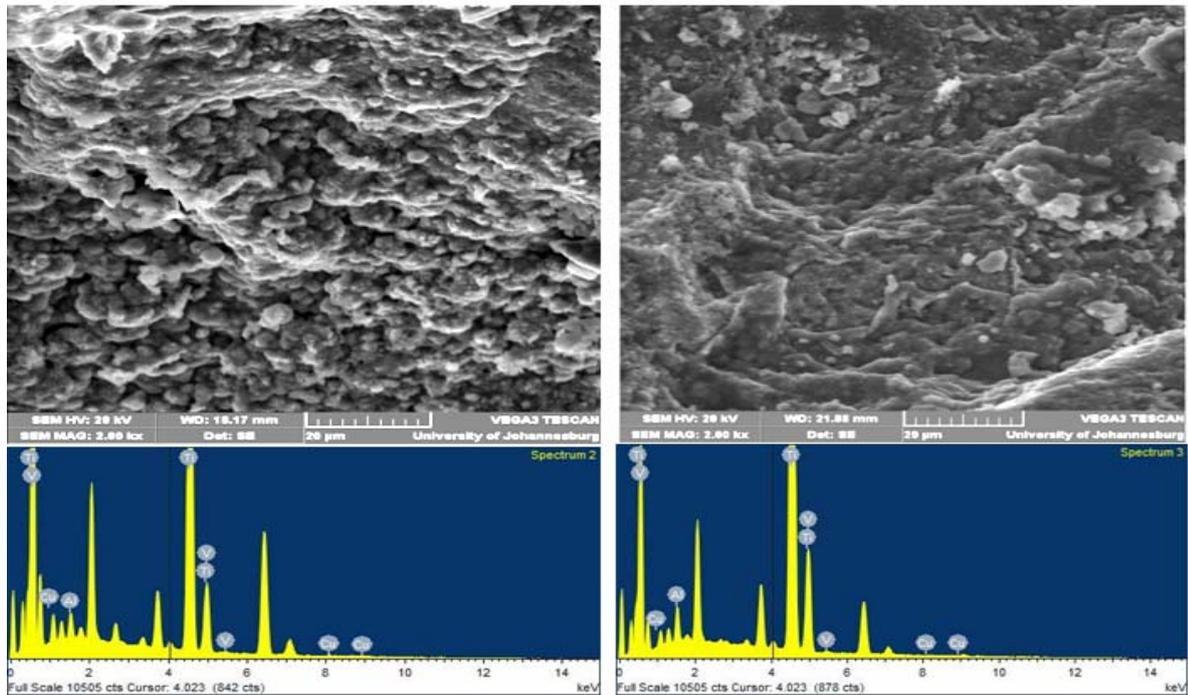


Fig. 3. SEM micrograph and the EDX analysis of Ti6Al4V/Cu composite surface after 2 weeks Hank's solution immersion (a) 900 W and 0.005 m/s; (b) 1200 W and 0.005 m/s

After the 2 weeks of immersion in the body fluid, the surface shows a bone-like structure with pores. The simulated body fluid was used in predicting the in vivo bone bioactivity as described by Kokubo and Takadama, 2006. The micrograph shows fracture topography with a porous bonelike structure. The pores observed allow the penetration of the body tissues through them. This structure is similar to the results of Xie and Luan, 2008 presented when hydroxyapatite-coated Ti6Al4V was characterized for medical implants. Very slight pitting corrosion was observed on some of the samples and exists as a result of the presence of chlorides in the Hank's solution which appreciably aggravates the environments for formation and growth of the pits through an autocatalytic process, accessed Wikipedia, 2014 on pitting corrosion. Cognizance needs were taken into consideration by Nava-Dino et al., 2012 in order to understand the behaviour of the material to chemical interaction with the body fluid environment for the human body stability. In other word, any metal for biomedical application should demonstrate excellent pitting and crevice corrosion resistance in body fluid as stated by Bidhendi and Pournavari, 2011. The EDS result shows the presence of Ti, Al, V and Cu. Titanium shows the highest peak and has a weight percent (wt %) of 95.37. The wt % of Al, V and Cu are 2.82 wt %, 1.69 wt % and 0.12 wt % respectively. The wt % of Cu was small due to the 1 % added to the Ti6Al4V and this could alter or distort the lattices of Ti6Al4V structure.

3. Conclusion

Titanium and its alloys have been proved to exhibit a good corrosion resistance due to their high affinity for oxygen when exposed to the environment. In this study, the immersion of Ti6Al4V/Cu composites in the Hank's solution was successfully conducted. The composites show the formation of bone-like and fracture-like structures under the SEM after 2 weeks of immersion in Hank's solution. Pitting corrosion was slightly observed in the sample deposited with a laser power of 1200 W and scanning speed of 0.005 m/s.

The addition of very little quantity of Cu has been tested to improve the strength of the implant to the bones. Further work needs to be done so as to prove the sustainability and durability of the composites when inserted into the body of human or animal for medical applications.

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References

- Aoki, T., Okafor, I. C. I., Watanabe, I., Hattori, M., Y. Oda, Y., Okabe, T., 2004. "Mechanical properties of cast Ti-6Al-4V-XCu alloys", *Journal of Oral Rehabilitation* 31, p. 1109.
- Bidhendi, H. R. A., Pouranvari, M., 2011. Corrosion study of Metallic biomaterials in simulated body fluid, *Journals of Metallurgical & Materials Engineering* 17, p. 13-22.
- Erinosh, M. F., Akinlabi, E. T., Pityana, S., 2014. "Laser Metal Deposition of Ti6Al4V/Cu Composite: A Study of the Effect of Laser Power on the Evolving Properties" World Congress of Engineering (WCE), London, p. 1204.
- Gonzalez, J. E. G., Mirza-Rosca, J.C., 1999. *Journal of Electroanalytical Chemistry* 471, p.109-115.
- Kokubo, T., Takadama, H., 2006. "How useful is SBF in predicting in vivo bone bioactivity" *Biomaterials* 27, p. 2907-2915.
- Nava-Dino, C. G., López-Meléndez, C., Bautista-Margulis, R. G., Neri-Flores, M. A., Chacón-Nava, J. G., De la Torre, S. D., Gonzalez-Rodriguez, J. G., Martínez-Villafañe, A., 2012. "Corrosion Behavior of Ti-6Al-4V Alloys" *International Journal of Electro chemical Science* 7, p. 2389 -2402.
- The science of Loren Pickart, PhD, True Science, Anti-aging, "The essentials of copper", *Your Body's Protective and Anti-Aging Metal*. Accessed March, 2014.
- Pitting Corrosion, Wikipedia, Available on http://en.wikipedia.org/wiki/Pitting_corrosion. Accessed July, 2014.
- Titanium biocompatibility, Wikipedia, http://en.wikipedia.org/wiki/Titanium_biocompatibility. Accessed June, 2014.
- Xie, J., Luan, B., 2008. Microstructural and electrochemical characterization of hydroxyapatite-coated Ti6Al4V alloy for medical implants, *Journal of Materials Research* 23, p. 768-779.
- Zhang, X., Zheng, G., Wang, J., Zhang, Y., Zhang, G., Li, Z., Wang, Y., 2013. "Porous Ti6Al4V Scaffold Directly Fabricated by Sintering": Preparation and *In Vivo* Experiment, Hindawi Publishing Corporation *Journal of Nanomaterials* Article ID 205076, 7 pages <http://dx.doi.org/10.1155/2013/205076>.