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Microstructural evolution and corrosion properties of laser clad Ti-Ni on titanium alloy (Ti6Al4V)

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Abstract

The use of Titanium alloys (Ti6Al4V) is highly evident in applications such as aerospace, automobile, marine and petrochemical environments owing to their outstanding specific strength to weight ration and good corrosion properties. Although they have high strength useful for fabrication of engineering components and movable parts in a mechanical system, Ti6Al4V are restricted to non-friction applications as a result of their low hardness and poor wear resistance. In this work, TiNi intermetallic hard coatings on Ti6Al4V alloy via coaxial laser cladding method. The effects of laser processing parameters on morphological evolution, microhardness and electrochemical behaviour were studied. The phase present and microstructural evolution were characterized using X-ray diffractometry (XRD) and scanning electron microscopy coupled with energy dispersive spectroscopy (SEM/EDS) respectively. The corrosion behaviour of the synthesized hard coating was evaluated using potentiodynamic polarization technique in 0.5M H_2SO_4. The microstructures showed no evidence of porosity, crack or initiation of stress.

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Keywords: Corrosion; Laser; Micro-hardness; Titanium-Alloy

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1. Introduction

Ti6Al4V alloys are characterized by desired and useful combination of exact bulk properties. The properties consist of low-density which provides good strength to weight ratio, high specific strength and good corrosion resistance properties in many environmental conditions [1]. Other properties are outstanding high temperature resistance and biocompatibility [2-4]. As a result, titanium alloys (Ti6Al4V) find broad applications in the aerospace, automobile, chemical, marine, petrochemical and engineering industries mostly for manufacturing of airframes and undercarriage components [3, 4]. Nevertheless, Ti6Al4V alloy applications are restricted to non-friction occasions due to the low hardness and poor wear resistance properties. Hence, more demands for new materials with enhanced properties under harsh operating conditions are increasing.

Surface alteration of materials such as steels, titanium alloys, aluminum alloys, etc. through cladding, laser surface alloying and hardening are becoming more increasingly popular due to its significant progression in industrial applications. Ceramics, metals and alloys are progressively studied in order to obtain fabrications of metal matrix composites (MMCs) on Ti6Al4V alloys [5]. These materials mainly act as binding phases between the matrix and the ceramic reinforced phases, which mostly reduce the chances of cracks successfully. In addition, they would perhaps partake in the chemical reactions for the period of laser cladding progression, resulting in intermetallic phases [3,6]. The choice of materials which are used for cladding are based mainly on desire to produce coatings which are hard and applicable for aerospace and marine application coating.

Mokgalaka, Popoola and Pityana [6], fabricated NiTi hard coating on Ti alloy control by means of laser metal deposition (LMD). From the results, the developed coatings showed the presence of NiTi, NiTi2 and NiTi3 intermetallic phases. Ti55-Ni45 coating was more resistant to corrosion, while Ti50-Ni50 and Ti45-Ni55 coatings follow in that series respectively.
In this study, the effect of Ni addition on Ti based coating on the surface of Ti6Al4V substrate under varying process conditions is investigated. Characterization of microhardness and electrochemical and microstructures were assessed and related with Ti6Al4V substrate.

2. Experimental method

Ni and Ti powders were homogeneously mixed in a Tubular Shaker Mixer and subjected to interaction of rotation. The powders were mixed for 8 hours at a rotational speed of 50 rpm. Table 1 denotes the chemical composition of the Titanium alloy which was used as a substrate.

Table 1: Chemical composition of titanium alloy substrate

Ti	Al	V	Fe	C	O	N
Balance	6.10	4.01	0.15	0.007	0.12	0.005

Sinar Continuous Wave Nd: YAG laser was used to clad the NiTi powders on the substrate and it was controlled by a KUKA robot which panels the direction of the cladding head. The mixed Ni and Ti powders were fed coaxially with a controlled powder feeder. The developed coatings specimens were grounded and polished on 120, 220, 600 and MD large diamond disc and later etched in krolls agent solution. The morphological evolution and phase identification was characterized using SEM-EDS and XRD respectively. The microhardness properties of the alloy was measured by means of Vickers Emco TEST DURASCAN. The corrosion behavior of the developed coatings were studied in 0.5 M H_2SO_4 by means of Autolab potentiostat equipped with nova software was used.

3. Results and discussion

Table 2 present the cladding pattern of the developed coatings. The applied power was kept constant and scan speed was varied

Table 2: Summarized Laser Processing Parameters of Ti-Ni coating.

Sample	Clad coatings	Power (W)	laser speed (m/min)	Beam diameter (mm)	Powder Feed Rate (g/min)	Gas flow rate (L/min)
A	Ti-10Ni	900W	0.6	3	1.0	1.2
B	Ti-10Ni	900W	1.2	3	1.0	1.2

3.1 SEM/EDS of the synthesized Ti-Ni coating.

Figure 1 and 2 shows SEM images of developed TiNi coatings. The coatings were fabricated at scan speed of 0.6 m/min and 1.2m/min at a laser power of 900W. The alteration in morphological evolution of the developed hard composite coatings was due to the difference in scan speed which leads to different solidification rates. Therefore, the difference in solidification techniques could lead to different morphology [7]. The fabricated coatings give rise to non-homogenous dendritic grains which showed no evidence of pores, cracks or initiation of stress. From Figure 1, larger dendrites size can be observed, this can be attributed to the fact that low scan speed could result in the substrate and the powders been exposed to heat for a longer period. In contrast, Figure 2 sample experienced fast cooling and there was minimal time grain growth, therefore the microstructure showed small dendrites grain size as compared to Figure 1 [8]. The presence of Ti, Ni and Al elements were detected by EDS and it is different as compared to the titanium alloy control.

Figure 3 represent the XRD pattern of the clad samples at Ti-Ni composition with 900W power and the laser scan speed of 0.6m/min. With respect to scan speed, the XRD spectrum of the 0.6m/min scan speed shows the major phases present on its peaks as NiTi and TiNi3. Major diffractions peaks of: 42.08^{o}, 43.29^{o} and 78.65^{o} and their inter-planar distance of 2.146 Å, 2.089 Å, and 1.215 Å respectively. The produced phases at 900W and altered laser scan speed are due to high temperature gradients synthesis of Ti powder present as intermetallic [9]. The results also displays that the fabricated clad layers has hard phases present which could result in improved microhardness.

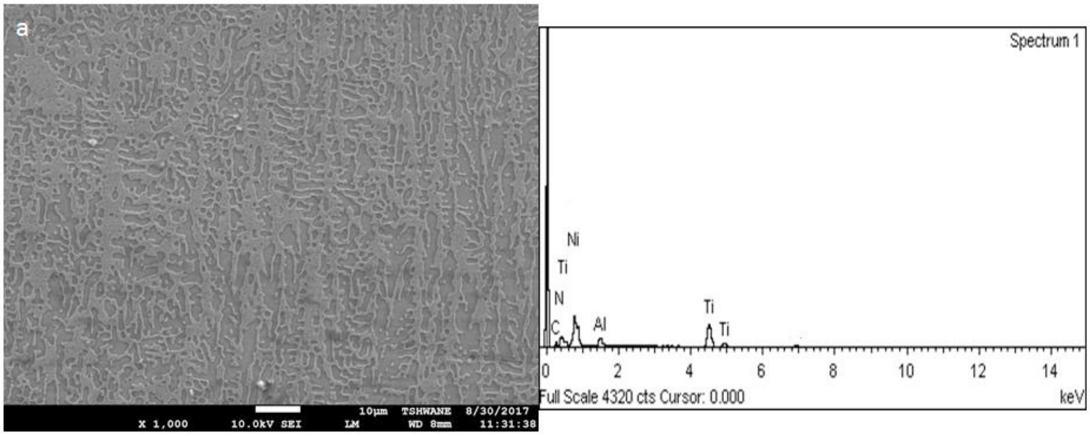

Figure 1: Ti-10Ni surface coating at 0.6m/min

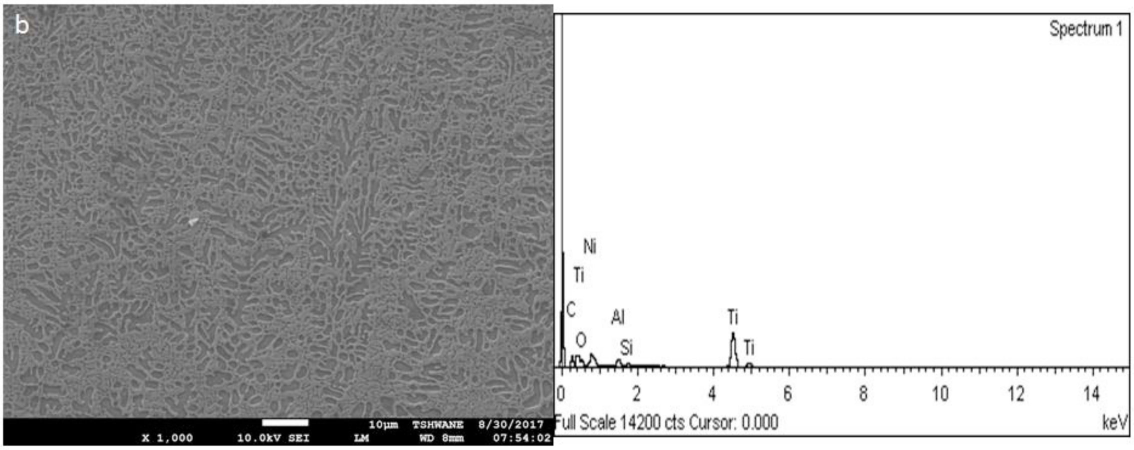

Figure 2: Ti-10Ni surface coating at 1.2m/min

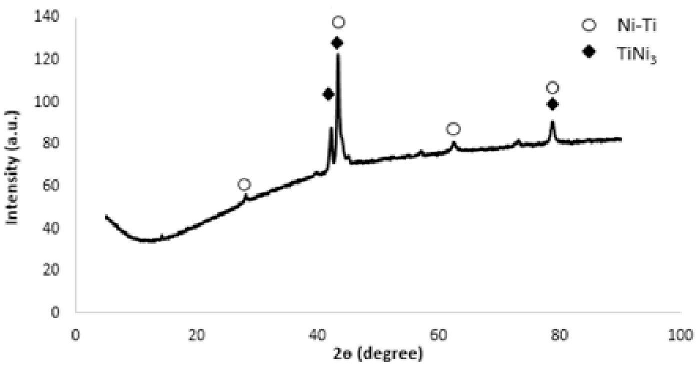

Figure 3: XRD spectrum of Ti-10Ni coating at 900W and 0.6 m/min.

Figure 4 present the microhardness properties of the developed coating g, HAZ and the substrate of the Ti-Ni clad layer at 900W and varying scan speed of 0.6m/min and 1.2m/min respectively. From the plot indicates, the hardness increases gradually from 345 HV of the Ti alloy substrate to 856 HV as the highest point it reaches at 1.2m/min scan speed followed by 823 HV at 0.6m/min. The microhardness was higher in the cladded region and decrease along with the increase in distance from the cladded surface. The rise of hardness near the substrate was due to heat treatment effect on the titanium alloy from the laser beam [7].

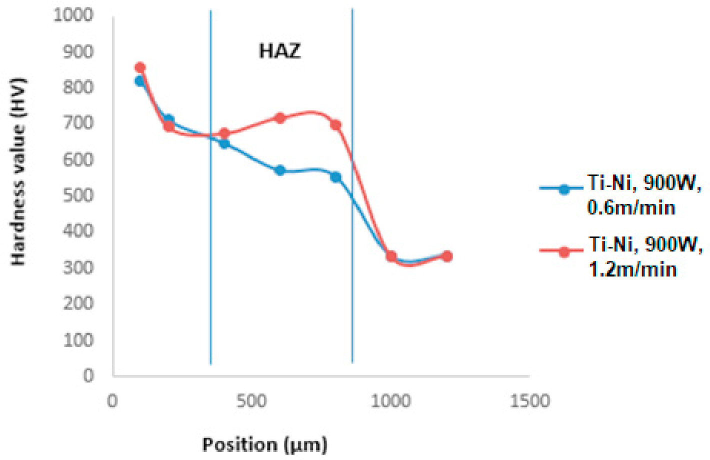

Figure 4: Microhardness profile of laser clad Ti-10Ni (900W) metallic coatings at 0.6m/min and 1.2m/min.

The plot below (Figure 5) also represents the potentiodynamic polarization of Ti-Ni ternary coating at varied laser scan speed of 0.6 and 1.2 m/min on Ti6Al4V specimen and table 3 shows the dynamic fit corrosion results of the fabricated coating. The visual representation of the synthesized behaviour was examined under 0.5M H_2SO_4 medium. From the results, it can be seen that the fabricated coating made at the high scan speed exhibited highest corrosion resistance with highest polarization resistance (Rp) of 1245.9Ω and the lowest corrosion current density of 1.70E-03 A/cm^2. The corrosion rate of the Ti-Ni fabricated coatings decreased from 0.07849mm/year at 0.6m/min to 0.02025mm/year at 1.2m/min enlightening the influence of laser scan speed on corrosion resistance properties by varying morphological evolutions of the developed alloy coatings. According to Mogoda et al. [9] and Mokgalaka et al. [6], corrosion of material is related to factors such as grain size of the microstructural evolution and chemical composition of the phases present in the alloy.

Table 3: Polarization Tafel data

Sample Name	Ecorr, Obs (V)	jcorr (A/cm²)	Corrosion rate (mm/year)	Polarization resistance (Ω)
Control	-1.7820	0.00838	0.949	50.01
Ti-10Ni 0.6 (900)	-0.12786	7.90E-03	0.091824	1132
Ti-10Ni 1.2 (900)	-0.07606	1.70E-03	0.035121	1245.9

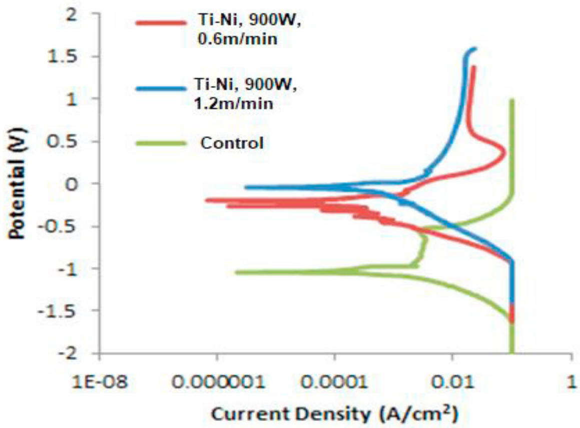

Figure 5: Comparative polarization curves of laser clad-deposited Ti-10Ni/Ti-6Al-4V coatings in 0.5M H_2SO_4 solution.

4. Conclusion

Ti-Ni coating was successfully developed on Ti6Al4V alloy with enhanced microhardness and electrochemical behaviour properties have been accomplished and therefore it is concluded that:

- ❖ The microstructure shows no evidence of porosity, crack or initiation of stress at both laser scan speed.
- ❖ The EDS of the matrix confirmed the existence of Ni, Ti, and Al.
- ❖ The microhardness of the developed coatings increased to maximum of 856HVN for Ni-Ti at 1.2m/min followed by Ti-Ni at 0.6m/min with 823HVN as compared to 345HNV of Ti6Al4V.
- ❖ Corrosion resistance properties of the developed coatings showed good corrosion behaviour as compared to Ti6Al4V

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