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Microstructure and Microhardness Characterization of Cp-Ti/SiAlON Composite Coatings on Ti-6Al-4V by laser cladding.

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Abstract

Failure of engineering components on application is mainly a result of poor surface behavior of materials under certain conditions. Titanium and its alloys have numerous beneficial properties including light weight, high strength and excellent corrosion resistance which have made them desirable in various industries. However, due to low hardness and poor wear resistance their industrial applications are restricted in harsh conditions. In this study Commercially Pure Titanium and SiAlON powders admixed at varied composition (98%Ti/2%SiAlON and 95%Ti/5%SiAlON) were used to fabricate composite coating on Ti6Al4V substrate by Laser cladding at altered scanning speed (0.6 and 1.2 m/min). The microstructures were examined using SEM/EDS and the phase evolutions were identified using XRD. The cross section microhardness measurements were carried out by means of a Vickers hardness tester. The results revealed improvement in the hardness property as compared to the unconditioned substrate. The coating average surface hardness values were about twice that of the as-received substrate which was attributed to the presence of hard phases such as Si_3N_4, TiN and SiO_2 as revealed on XRD.

Keywords: Cp-Ti/SiAlON; composite coatings; Ti-6Al-4V; Microhardness; Laser cladding

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1. Introduction

It is generally impossible to find a material that by itself possesses properties so as to completely satisfy all requirements of a specific application. The progressive deterioration of materials on industrial applications mainly on the surface may lead to reduction in process efficiency or on worst scenarios force a shut-down, this affects the economy outrageously. While Titanium and its alloys remains attractive to a wide range of applications, their poor wear resistance and low microhardness limits their applications. This materials' prominence is attributed to a combination of excellent characteristics such as high corrosion resistance, biocompatibility and high strength-to-weight ratio [1]. The latter has been a recent major concern to applications in the automotive and aerospace industry requirements for weight reduction due to the global warming alarms which is largely affected by weight in regard of fuel consumption [2].

The demand of new materials with superior properties for improved service performance under harsh operating conditions is ever-increasing and has since encouraged developments in plentiful surface modification processes in order to overcome material's surface deficiencies. Generally, coatings are fabricated on surfaces of cheaper metals or materials with desirable bulk properties but poor surface characteristics in order to make them more durable. Conventionally, various coating methods such as High Velocity Oxy-fuel (HVOF), Submerged Arc (SA), Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Shielded Metal Arc (SMA) welding suffer from numerous restrictions [3]. On the other hand, electroplating and plasma coating provide inadequate protection due to weak interfacial adhesion, micro-cracks, porosity and rough surface finish [4].

Laser cladding, a perfect candidate for enhancing Ti-6Al-4V surface behavior, is a promising surface modification technique and has since been a research hotspot as a result of a variety of distinctive benefits it offers over conventional methods. The above-mentioned advantages include high bonding, low dilution rate, a narrow heat-affected zone, process control, excellent control of the focused beam, microstructure control, minimal distortion of the substrate due to localized heating with low energy input as well as time and quality delivery [5]. In addition, this technique has the ability to locally deposit various metallic powdery materials to fabricate surface coatings of no discontinuity in chemical and mechanical properties. Above and beyond, this technique can also effectively fabricate metal-matrix composite coatings which are commonly used on Titanium alloy. Furthermore, MMCs are known to provide better protection than monolithic alloy. Several research works have been conducted on laser cladding of metal-matrix composite coatings in attempt to improve the effectiveness of the process. [6], [7].

SiAlON ceramics possess numerous attractive properties such as high hardness sustainable at high temperature, excellent thermal shock resistance, abrasion resistance, creep resistance and chemical inertness [8]. The above-mentioned benefits make this material a perfect candidate for the fabrication of metal/ceramic composite coating for surface performance enhancement. However, very little research has been undertaken with the aim of reaping the benefits offered by this material. In the current research, commercially pure Titanium and SiAlON admixed powders were co-deposited on Ti6Al4V surface by means of laser cladding in attempt to fabricate composite coating with enhanced properties.

2. Experimental

2.1. Materials Preparation

The build plate material used in the present study was Ti-6Al-4V alloy with the composition shown in Table 1. The substrate plates of 7mmX72mmX5mm dimensions were sand blasted by SiO2 grit sand in order to remove the unwanted material on the uppermost layer of the material and to attain a uniform surface finish with least reflection to enable absorption of laser energy. This was followed by cleaning with acetone and drying in hot air prior to laser cladding. The powders used as feedstock for this work are commercially pure titanium and SiAlON of particle size ranging from 100micron to 45micron. The microstructures of the substrate were evaluated using SEM/EDS. The powders were weighed and mixed by a turbula mixer to achieve homogeneity prior deposition.

Table 1: Elemental composition of the Ti-6Al-4V alloy substrate.

Element	H_2	N_2	O_2	Fe	C	Al	V	Cu	Si	Y	B	Ti
Composition	0.0003	0.005	0.18	0.2	0.012	6.2	3.9	<0.02	<0.03	<0.005	<0.003	Bal.

2.2. Laser Deposition and Process parameters

The Cp-Ti/SiAlON composite coatings of 98wt. % Ti / 2wt. % SiAlON and 95wt. %Ti / 5wt. % SiAlON compositions were laser cladded on the Ti-6Al-4V substrate using 4.4 kW continuous wave (CW) Rofin Sinar Nd:YAG laser fitted with an off-axis nozzle for feeding powders. The laser power, powder feed rate, beam diameter and beam diameter were kept constant at 900W, 1g/min, 3mm and 1.2L/min, respectively while the laser scan speed used was 0.6 and 1.2.m/min. The cladding atmosphere was shielded by argon gas to prevent oxidation as well as to prevent of contamination and formation of blowholes. The powder compositions and the laser cladding process parameters are shown in the Table 2 below:

Table 2: Summary of the laser processing parameters and admix powder compositions.

Sample No.	Admix Powder Composition	Laser Scan Speed (m/min)	Laser Power (W)	Powder Feed rate (g/min)	Beam diameter (mm)	Gas Flow rate (L/min)
1.	98 wt.%Ti-2 wt.%SiAlON	0.6	900	1	3	1.2
2.	98 wt.%Ti-2 wt.%SiAlON	1.2	900	1	3	1.2
3.	95 wt.%Ti-5 wt.%SiAlON	0.6	900	1	3	1.2
4.	95 wt.%Ti-5 wt.%SiAlON	1.2	900	1	3	1.2

2.3. Microstructural characterization and phase identification

Once deposition was achieved, samples were prepared by grinding with P320 grit SiC paper, Aka-rhaco and polishing. The Scanning Electron Microscope with Energy Dispersive X-ray Spectrometry (SEM/EDS) was used to capture micrographs and for the identification of the elemental species present on the sample. The X-ray diffractometer was used to evaluate the phases present in the composite coatings.

2.4. Microhardness Measurements

The micro-hardness measurement of the as-received Ti-6Al-4V substrate and the coated samples were studied using Vickers hardness tester using a load of 100g with retention time of 15 seconds. The Vickers hardness measurements were taken on the cross section of the samples in order, 20 indents were taken sequentially from the surface of the coating through coating/substrate interface and the heat-affected zone towards the bulk of the substrate.

3. Results and Discussions

3.1. Microstructure

In titanium alloys, elemental additions stabilize either the alpha phase or the beta phase with some additives having no influence on the phase constitution. Figure 1 depicts a micrograph of Ti-6Al-4V alloy showing a typical dual phase microstructure of the alpha (darker regions) and beta (lighter regions) phases, stabilized by aluminium and vanadium respectively. The thermal history and composition of an alloy are determinant of the microstructures of laser clad coatings, hence the mechanical properties. According to Vrancken et al. [9], the heat flows from the liquid melt pool towards the substrate and results in planar solidification in pure metals. However, the addition of alloying elements results in constitutional undercooling as a result of solute redistribution which causes dendritic solidification. Therefore, predicting the evolution of the microstructural features is commonly a challenge thus experimental evaluation is vital.

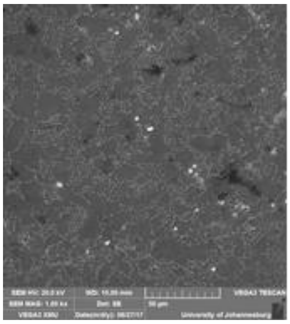

Figure 1: SEM micrograph of Ti-6Al-4V alloy substrate.

Figure 2 presents the surface view microstructures of the novel Cp-Ti/SiAlON composite coatings deposited at a laser scan speed 0,6 and 1,2m/min, respectively. It is noted that all coatings reveal a martensitic microstructure consisting of a needle-like acicular phase with some contents of beta phase. This is indicative of rapid cooling resulting from localized in situ heating from above the martensite start and the beta transus temperatures [10]. However, the coatings reveal an inconsistant distribution of the martensitic microstructure which can be attributed to alloying addition (SiAlON) which is in line with an observation by [6]. Figure 2a) reveals grooves on the surface of the coatings which can be attributed to high peak temperature developed through slow cooling as a result of a slow scan speed. Figure 2b) shows a surface with a refined microstructure with the needle like structure distributed throughout the sample.

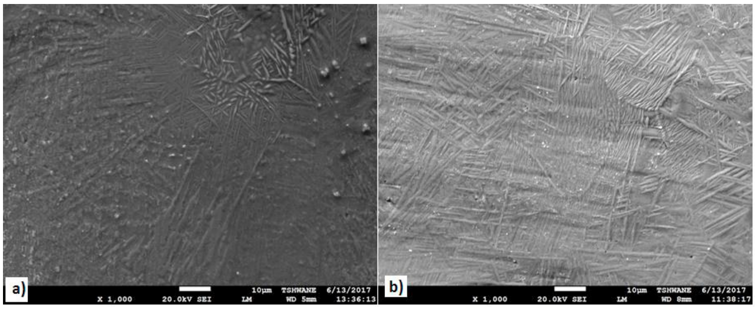

Figure 2: SEM micrographs of 95Ti-5SiAlON coatings' surface deposited at scan speed a) 0,6m/min and 1,2m/min captured at the surface.

Figure 3a) and b) shows the microstructural cross-sectional view of the Cp-Ti/95wt.%SiAlON laser cladded at two different scan speeds, 0.6 and 1.2m/min. Both samples revealed defects at the coatings/substrate interface, with Figure 3a) revealing an interface which seems to have complete melting with some portions over melted and Figure 3b) showing an interface with microstructure revealing what seems to be incompletely melted powder.

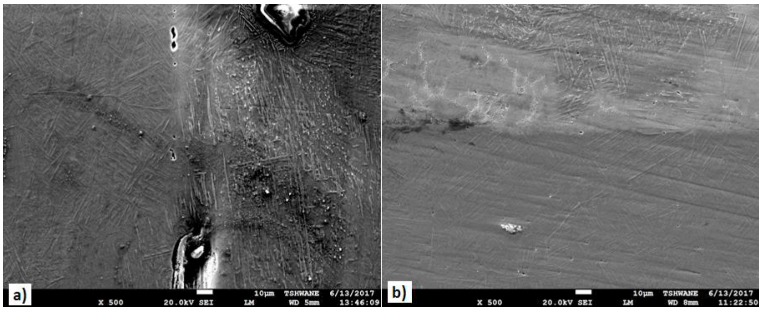

Figure 3: SEM micrographs of the cross-sectional view of 95Ti-5SiAlON coatings deposited at scan speed a) 0,6m/min and 1,2m/min captured at the coating/substrate interface

These observations can be attributed to enormous differences in thermal properties (thermal conductivity, capacitance and melting points) of the admixed powders (Cp-Ti and SiAlON). These phenomena can be explained as follows, ie, the titanium contents were molten in both conditions with SiAlON sufficiently molten in Figure 3a) and partially molten in Figure 3b). However, the temperatures high enough to melt SiAlON may have led to the segregation of constituents during melting since the solidification temperatures of these materials are far apart.

3.2. Phase Evaluation

The XRD spectra of the developed composite coatings is shown in Figure 4. The evolution of hard phases and titanium aluminide intermetallic phases including TiO_2, TiN, Si_3N_4, SiO_2 and AlN is clearly shown in the XRD profile. The increase in scan speed resultant in the formation of additional phases which serves as proof of SiAlON dissociation thereby confirming that process parameters govern metallurgical reactions and the rates they occur between the matrix and the reinforcement materials within the melt pool. It is these phases that are responsible for the enhancement of surface properties.

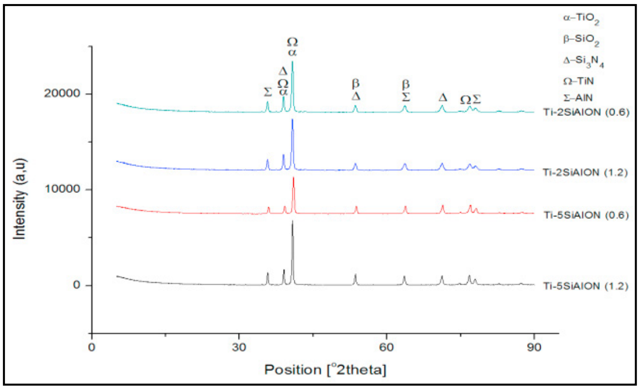

Figure 4: XRD Spectrum of Ti-SiAlON composite coatings

3.3. Microhardness

The microhardness distribution of the as-received Ti-6Al-4V and Cp-Ti+SiAlON from the surface coating towards the substrate along the cross-sectional view is compared and represented in Figure 5. The microhardness profile reveals the improved hardness values at the surface of the coating which rapidly decreases at the Heat affected Zone until it becomes relatively constant at the substrate region. Clearly, all the coatings significantly improved the microhardness of Ti-6Al-4V alloy substrate. The average microhardness of the coatings cladded at 0,6m/min and 1,2 m/min was 697HV and 790HV, respectively. The increase in microhardness of all the coatings was about twice that of as-received substrate. The microhardness of the 98Ti+2SiAlON and 95Ti+5SiAlON cladded at 0,6m/min were poorer than the counterparts cladded at a higher scan speed of 1,2m/min. This is attributed to rapid cooling achieved at 1,2m/min due to shorter beam-material interaction periods as a result of higher scan speed. The increase in SiAlON content from 2% to 5% also enhanced the microhardness of the coatings. This improvement was attributed to the increase in the content of the hard phases such as TiN, Si_3N_4, AlN and SiO_2 evolving during deposition. The highest microhardness value achieved was 819HV deposited at 1,2m/min with a 5% SiAlON content.

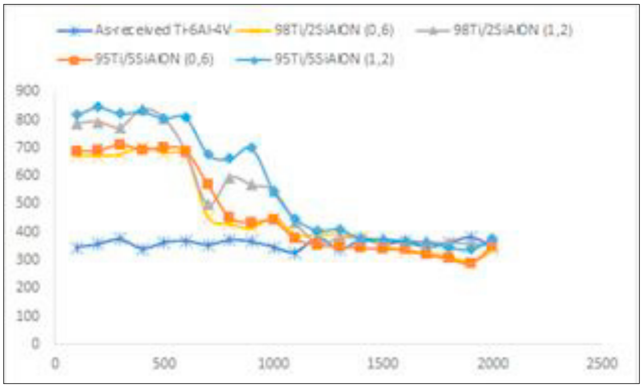

Figure 5: Microhardness variation along the cross-sectional view of the Ti-SiAlON coatings.

4. Conclusion

The Ti-SiAlON composite coatings were successfully fabricated on the Ti-6Al-4V where improvements in microhardness property was achieved. The microstructural analyses reveal a martensite microstructure consisting of a needle-like acicular phase with some contents of beta phase. These enhancements were found to be greatest at high reinforcement material content (SiAlON) when using high laser scan speed which was seen as proof of increment in cooling rates thereby refining the microstructure.

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