Effect of Laser Power on the Microstructure and Microhardness Property of Hybrid Fabricated Ti6Al4V Based Metal Matrix Composite

Ochonogor O. F, Esther T. Akinlabi, *Member, IAENG,* and Didier Nyembwe

***Abstract*— Several surface coatings on Ti-6Al-4V alloy using laser treatment technique have been investigated in this paper. A hybrid Ti-6Al-4V based metal matrix composites system was also successfully fabricated. This was possible using three hoper system which contained 3.8 vol. % of Ti-6Al-4V and a small amount 0.1 B_4C and 0.1 BN respectively. Two different laser powers "2000 W and 1400 W with scanning speed of 1.0 were employed. The idea of these powder coatings and reason for investigating the different Laser power is to evaluate the influence of laser power on the surface morphology and hardness property of Ti-6Al-4V/B_4C/BN alloy systems. The hardness result of experimental showed a general improvement. The hardness revealed that the Ti-6Al-4V/B_4C/BN system fabricated at 2000W showed a hardness improvement as high as 640.4 $HV_{O.5}$ compared to the as receive Ti-6Al-4V substrate Hardness value of about 357.3 $HV_{O.5}$ and that of 1400W recorded a hardness value of 886 $HV_{O.5}$. The percentage increase from the as received Ti-6Al-4V alloy was 147.9% and 79.2% respectively. Problems to be solved and the prospective application of laser modification of the hybrid titanium alloy formed were also highlighted.**

***Index Terms*— Ti6Al4V Substrate alloy, Ti-6Al-4V, B_4C and BN powder. Laser Coating**

I. Introduction

Various surface treatments have been used to improve the mechanical properties of Ti-6Al-4V alloy. Surface treatments such as laser nitriding and tin coated surface treatment on Ti-6Al-4V alloy surfaces have been investigated to further improve the mechanical properties of Ti-6Al-4V alloy for effective applications. These techniques have been demonstrated to form nitride rich compounds on the surface region of materials to form a hard surface and improve their tribological properties. A typical example is the TiN PVD coated surface which has been proven to reduce the surface roughness of material thus forming hard, improved surface properties with increased elastic modulus of the treated layer [1]. Fabrication of active films is however needed on the surface of titanium alloys to further improve compatibility often carried out by laser coating. These processes potentially eliminate cracks and other defects such as porosity and cavities.

Laser coating involving the use of Laser beam is focused onto metallic surface to perform a broad range of treatments such as remelting, alloying and cladding. Thermal-barrier coatings like refractory-oxide ceramic coatings applied to the surfaces of metallic parts may have application in the hottest part of gas-turbine engines [2]. TBCs provide thermal insulation to the metallic/super alloy engine parts [3].

Titanium and its alloy exhibit attractive and interesting properties, most importantly in terms of their mechanical properties [4]. Despite the poor thermal conductivity and accelerated tool wear during manufacturing of these special alloys, they have shown potential for excellent application both in aero engines and industrial gas turbine [5]. The performance of titanium-based composite materials enables its application for structural parts of rockets, aero engines, and turbojet engines [6, 7]. However the application of this alloy for Turbine engines/industrial turbines has remained a challenge as the turbine temperature correlates to the capacity and selected alloying material for reinforcement [8, 9]. In other to avoid problems such as defects, crack, porosity which may lead to break down of system at high temperature above 1000ºC, a good thermal, fatigue resistant, creep strength and high cycle fatigue material is however needed since their operation requires a very high temperature [10-12]. These properties can only be obtained through intrinsic material resistance which is enhanced by application of protective coatings on their surfaces. There has been new technologies which has been used to modify the surfaces of alloys with limiting factor of producing thin surface layers, these technique includes; laser nitriding, laser cladding, electron beam radiation processes etc., their limitations has been linked to costly manufacturing procedures, vacuum chambers, and expensive initial investments [21].

The fabrication of high thermal resistant material have now evolved from the conventional casting to direct solidification processes resulting to overall improvement in mechanical properties. Various surface modification technique including, effect of laser processing parameters on the resultant surface properties of titanium alloys has also been reviewed in this paper.

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II. CURRENT STATUS ON VARIOUS COATED TI-6AL-4V ALLOY USING LASER TREATMENT TECHNIQUES

Filip, 2008 [13] investigated laser nitriding surface layer of Ti6Al4V alloy. The surface roughness and the Vickers hardness under load of 1.96 N were carried out on the cross sections of surface layer. The results however indicated that the Laser remelting process produced a hard surface layer of ceramics particles of TiN and Ti2N phases in martensitic matrix. The hardness of surface layer also revealed a significant increase compared to the untreated alloy which was attributed to the formation of TiN and Ti2N particles. The maximum hardness value of the laser treated surface was about 1500 $HV_{0.2}$. The wear resistance of laser nitrided layer remarkably increased compared to the as received material.

Kim et al., (2014) [15] carried out Laser Surface Modification of Ti and TiC Coatings on Magnesium Alloy in order to enhance its surface properties. The substrate specimens were cut from a rolled sheet, and then the Ti and TiC coatings were deposited on sand blasted untrasonic cleaned AZ31 alloy substrates through air plasma thermal spray. The TiC spray coating was carried out in situ reaction between elemental Ti and carbon powders after ball mixing. A combination of Ar and H_2 was used as the plasma gas and Ar was used as the powder carrier gas. The pre-deposited Ti or TiC coatings on the specimens were then surface treated using a continuous wave (CW) diode laser. The applied power for the laser treatment was between 100 to 300 W, and scanning speed was 14 mm/s. For oxidation to be avoided during the process, an inert gas (Ar) was continuously bellowed into the melting zone. Various microstructural analysis were performed using SEM, equipped with energy dispersive Xray spectrometer (EDS), and Xray diffractometer (XRD). Surface melting process application by plasma spraying of Ti or TiC on AZ31 alloy revealed the formation of fine Ti particle dispersed surface layer on the substrate. It was however reported that hardness showed a significant improvement for the laser treated specimens when compared to the untreated AZ31 alloy. In the plasma sprayed specimen, there was an incomplete TiC formation while the completely transformed TiC layer was recorded after post laser melting process. Result also revealed that the laser post treatment induced enhanced adhesion strength between the coating and the substrate.

Filip et al., 2006 [16] attempted to study the effect of heat treatment on microstructural properties as it influences the strength of a material. The experiment involved two titanium alloys which were (i) Ti-6Al-4V, and (ii) Ti-6Al-2Mo-2Cr. It was however observed that the heat treatment resulted to a wide variation in properties. The properties like yield stress, tensile stress and ductility were remarkably improved through a bimodal microstructure, as the region having lamellar microstructure was characterized to have a combined high fracture toughness and high fatigue crack propagation resistance.

In a recent experiment involving the mixture of Zirconium powder with PVA and cold glue as binder. These coatings were used as reinforcement to improve the surface properties of Ti-6Al-4V alloy [16]. A laser cladding experiment carried out by irradiating the pre-placed powder bed at 500 W laser power, 10mm/s Scan speed and of 1 mm beam spot size. Powder mixture was melted to form a thin layer that is bonded to the Ti6Al4V substrate by a process known as irradiation to form a zirconium + zirconia composite due to in-situ reaction observed in the liquid state. The observed microstructure revealed some small pores and cracks. At lower magnification, coatings were dense and crack-free, and non-porous microstructures were achieved. It was however reported that the presence of binder in the Zr powder revealed a change in microstructure and resulted to a significant increase in the hardness of the coated Ti6Al4V alloy from the Cladded layer down to substrate of the sample. It was also observed that Zr + PVA binder coating was deposited uniformly with lesser dendritic structure in comparison to Zr without binder and Zr with cold glue. Manufactured Ti6Al4V alloy coatings with zirconium and zirconia composite were however observed to have improved the base material's resistance to corrosion and wear as reported.

III. EXPERIMENTAL PROCEDURE

A hybrid Ti-6Al-4V/ B4C/BN system was fabricated at two different Laser power. 2000W and 1400W respectively. The Scanning speed was kept constant at 1.0 and powder flow rate of 3.8 Vol. % of Ti-6Al-4V, 0.1 Vol. of B4C and 0.1 Vol. BN. The effect of Laser power was investigated as it influenced the microstructure, surface roughness and hardness of the two hybrid systems formed.

TABLE I
PROCESSING PARAMETERS

Sample	Laser power	Scanning Speed	Powder flow rate (Ti64)	Powder flow rate (B_4C)	Powder flow rate (BN)
1	2000	1.0	3.8	0.1	0.1
2	1400	1.0	3.8	0.1	0.1

IV. RESULTS AND DISCUSSION

Fig. 1 Presents an optical micrographs of formation of microstructures of titanium matrix composites obtained at 2000W with combined particle distribution of Ti-6Al-4V/ B4C/BN, the microstructure revealed more melted reinforcement particles with lesser particle distribution compared to the coating carried out at 1400W. A few pores were evident as observed in Fig. 1 (a) and Fig. 1 (b) respectively.

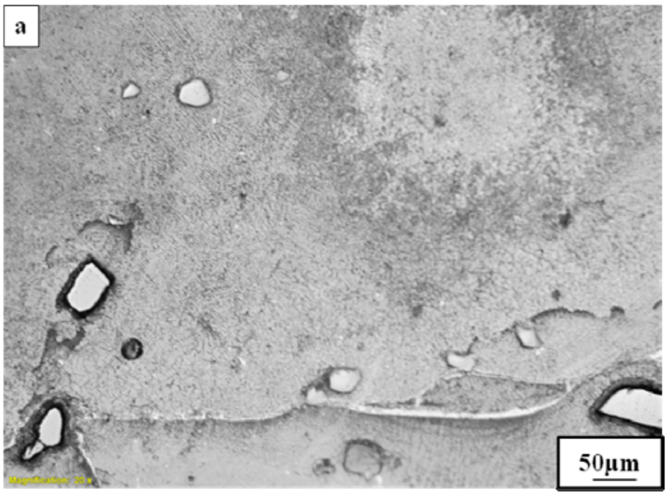

Fig. 1. (a) 2000W, 3.8 Ti-6Al-4V+0.1 B4C+0.1BN

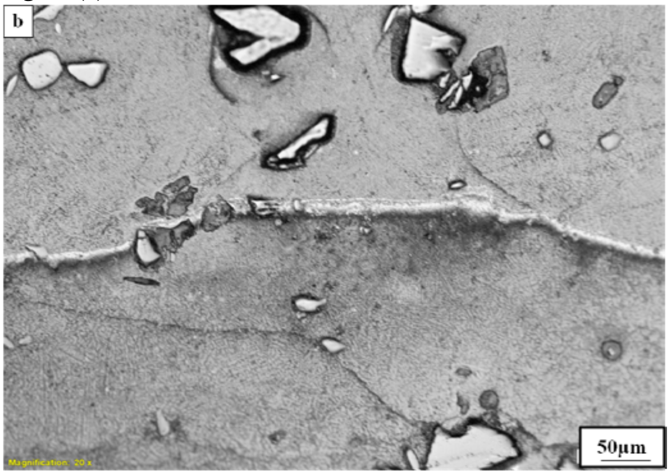

Fig. 1 (b) 2000W, 3.8 Ti-6Al-4V+0.1 B4C+0.1BN

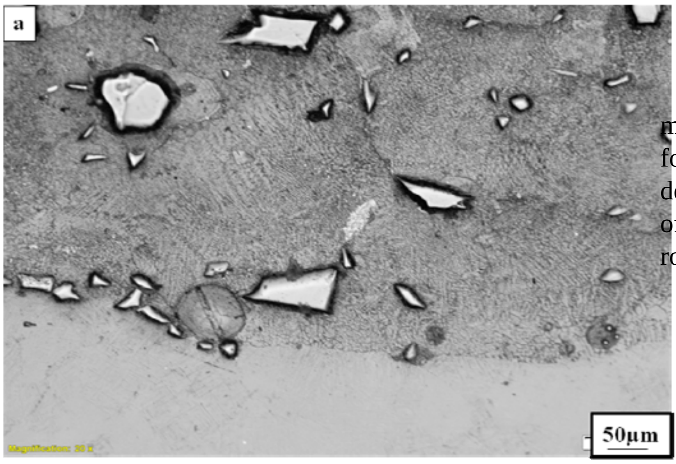

Fig. 2. (a)1400 W, 3.8 Ti-6Al-4V+0.1 B4C+0.1BN

Fig. 2 (a) revealed that the bonding strength between the surface clad layer and the substrate was very high and homogeneous. This was also shown in Fig. 2 (b) Acicular martensite was formed at the Heat affected Zone (HAZ) [20] and a more uniform distribution of reinforcement particles was also observed.

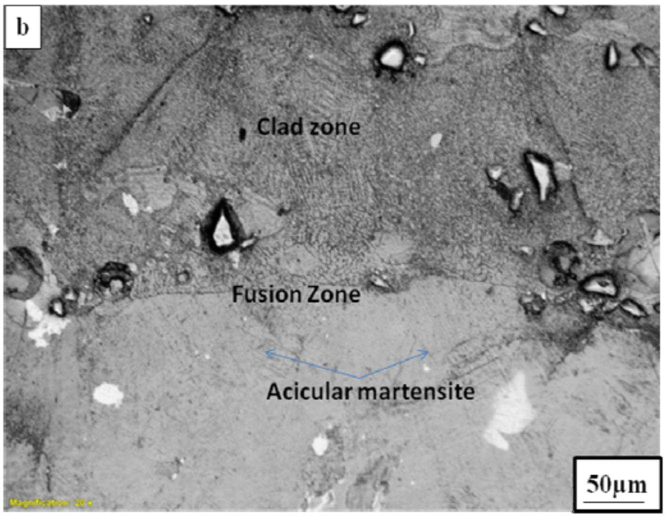

Fig. 2. (b) 1400 W, 3.8 Ti-6Al-4V+0.1 B4C+0.1BN

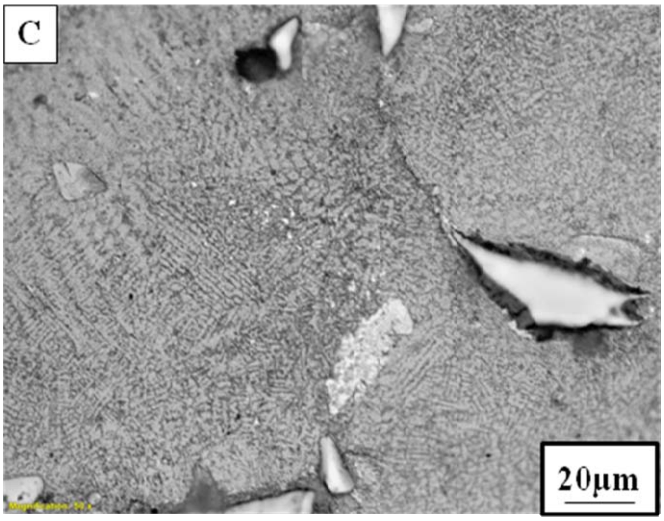

Fig. 2. (c) 1400 W, 3.8 Ti-6Al-4V+0.1 B4C+0.1BN

Fig. 2 (c) shows clear martensite in the niddle like manner. This formation of hard microconstituent has been found to be a determining factor for the high hardness deduced from the hardness profile in fig. 3. The formation of martensite in the case was due to the rapid cooling to room temperature [19].

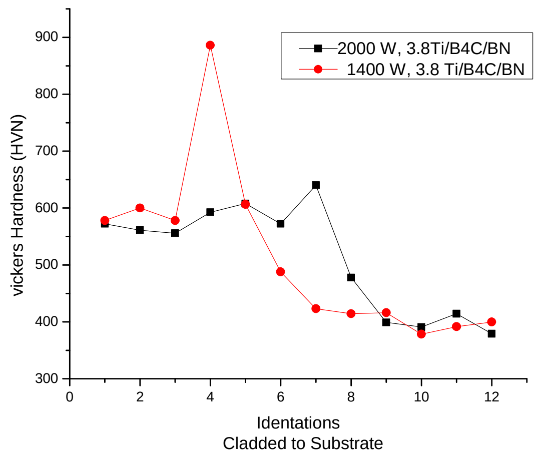

Fig. 3. Hardness value of Ti-6Al-4V+ 0.1 B4C+ 0.1BN at different fabricated temperature.

The hardness profile at lower laser power revealed a general increase in the hardness value of the coated area. A sharp increase in hardness value before reduction as it progresses towards the substrate, at the forth point of indentation could be attributed to the unmelted solid carbide particle embedded in the matrix as represented above. The second profile represented with black dotted line also showed a general increase in the hardness value though lesser in Hardness value which could be attributed to a more melted and weakened carbide particle due to high laser power. See table II

TABLE II
PROCESSING PARAMETERS AND AVERAGE HARDNESS VALUE OF FABRICATED COMPOSITE.

Sample	Laser power	Scanning Speed	Powder flow rate (Ti)	Powder flow rate (B_4C)	Powder flow rate (BN)	$HV_{0.5}$
1	2000	1.0	3.8	0.1	0.1	640.4
2	1400	1.0	3.8	0.1	0.1	886

V. Conclusion

In conclusion, Laser cladded Ti-6Al-4V/B4C/BN was successfully fabricated.

The influence of laser power on the surface morphology, hardness property has been investigated. The bonding strength and particle distribution of the fabrication at 1400W was excellent. This will enable thermal protection as required for the development of laser surface modified titanium alloy in the aerospace industry. It therefore suggests that the fabricated component could have application in high temperature condition i.e. in turbine parts.

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