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Wear Resistance and Morphological Characterization of High-power Laser Clad Coatings on Ti-6Al-4V Alloy

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Abstract

Ti-Si binary coatings were cladded on Ti-6Al-4V alloy surface for improvement morphological orientation, microstructure and surface properties. The coatings were developed at 2.1 kW power, laser scanning speed of 1.2, 1.6 and 2.0 m/min, spot diameter of 3 mm and 0.5 overlap ratio. An optical microscope was used to magnify and analyse the microstructural arrangement and a microhardness indenter used to measure microhardness at 100gf for 10 seconds. The indent spacing was maintained at 100 µm between adjacent indents. The phase content of the coatings was analyzed with XRD technique. The coating wear resistance was tested at 10N force loading for 7 minutes using a TRB tribometer and characterized using SEM. Clad coatings were observed to exhibit refinement in microstructure with an increase in laser scanning speed where transformation occurred from equiaxed grains with localized smaller grains to refined grain structure. The highest degree of refinement was observed at 2.0 m/min scanning speed. It was also found that the microhardness property was improved by 2.44, 2.60 and 2.64 times the microhardness of Ti-6Al-4Vat 342.3 $HV_{0.1}$. It is understood that high microhardness values favor improved wear resistance behavior. XRD analysis on the coatings revealed presence of Ti_5Si_3, Ti, Si and $TiSi_2$ phases where Ti and Si are in matrix capacity and Ti_5Si_3 and $TiSi_2$ present as intermetallic phases. The reported improvement in microhardness was attributed to the presence of Ti_5Si_3 and $TiSi_2$. The action of the laser scanning speed was found to influence the clad height where an increase in laser scanning speed resulted in a decrease in clad height in the order 685.9, 491.4 and 291.5 µm for 1.2 m/min, 1.6 m/min and 2.0 m/min respectively. Wear test indicated that the coatings displayed an improved wear resistance by evidence of little material removal exhibited, compared to the substrate material which was dilapidated by severe adhesive wear and further aggravated by plastic deformation.

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1. Introduction

Surface modification technology for metallic materials is regarded as one of the most efficient technologies for improvement of material properties, particularly titanium [1]. The surface limitations of titanium necessitate the need for surface modification. A more reliable way of solving material limitations of titanium alloys is through surface modification alloying with other metallic materials and surface alloy coating [2] where silicon is seen as a viable choice. [3] Refers to alloying of titanium with silicon to be low cost route where according to [4] titanium and titanium silicide phases such as Ti_3Si and Ti_5Si_3 are subsequently formed. Ti-Si alloys are considered to possess potential for high temperature applications due to the presence of Ti_5Si_3 intermetallic compound [5]. Ti_5Si_3 boasts properties such as oxidation resistance [6,7] low density [6,7,8], high melting point and high temperature strength [6,7].

Alloying of titanium and silicon to form surface coating can be achieved by laser cladding surface modification technology. This material processing route is adopted as it is well compatible with titanium surfaces and components [9]. This technology has the added advantage of the capacity to be used for repair and fabrication of complex parts with complicated geometries [10]. Laser cladding employs a laser beam to modify the surface and to give rise to desired metallurgical effects by cladding with a melted powder layer [11]. Of the different lasers that can be utilized for material processing. Nd: YAG if the most commonly used due to its excellent absorptivity and high precision [12].

Processing parameters such as laser scanning speed, powder feed rate, laser power, and spot size are critical in laser cladding as varying combinations of these parameters have the potential to give rise to different metallurgical effects on clad characteristics and geometries. Consequently, improper combinations of the said parameters can prove detrimental by yielding residual stresses within the material [13]. In present study, Ti-Si binary alloy coating are fabricated on titanium alloy Ti-6Al-4V at deposition high power to effect microstructural transformation and improvement surface and mechanical properties. Consequently, the microstructural and morphological nature, microhardness and wear resistance property were studied and discussed**.**

2. Experimental Procedure

Ti-6Al-4V alloy sheets of thickness 72×72×5 mm were used as substrate material for deposition. Titanium (Ti 99.9 wt.%) and Silicon (Si 99.9 wt.%) atomised spherical powders were used as alloying material. Ti-6Al-4V alloy sheets were sand-blasted for removal of foreign surface materials and further cleaned with acetone prior to laser deposition. Cladding was carried out using a co-axial 3 kW Rofin Sinar DY044, Continuous Wave Nd: YAG laser mobilised by a KUKA articulated robotic arm. The powder feed ratio was maintained at 1:1 Ti:Si ratio via 2 feed hoppers. Deposition power of 2.1 kW , laser scanning speeds of 1.2, 1.6 and 2.0 m/min and overlap ratio of 0.5 were utilised to form 60 mm coating beds were the beam diameter was 3 mm. Argon gas was used as precursor gas to create a non-oxidizing atmosphere during deposition. Figure 1 represents a summary of Cladding parameters.

Table 1: Laser Cladding parameters for deposited coatings

Sample No	Laser Power (kW)	Transverse Speed (m/min)	Powder ratio	Spot Diameter (mm)
1	2.1	1.2	1:1	3
2	2.1	1.6	1:1	3
3	2.1	2.0	1:1	3

Laser clad coating were section and mounted using Aka Resin Phenolic SEM Black Conductive resin and subsequently grinded at P320, P600, P800, P1000, P1200 and P2000 and polished with MD-Largo and MD-Chem OP-S polishing cloths employing a Diapro diamond suspension at 2 minutes run intervals to produce smooth and mirror-finish surface prior to etching using Kroll's reagent for 3-10 seconds. An Olympus BX51M Optical microscope with Olympus essential image evaluation software was used for microstructural evaluation and coating thickness measurements. SEM/EDS were conducted on sample coating surface for morphology, microstructure and identified elemental species. X-ray diffraction (XRD) was conducted for phase determination using PANalytical XRD analysis equipment. Transverse microhardness profiling on the coatings was done across the 3 areas on interest in Coating, Heat Affected Zone (HAZ) and substrate. Microhardness was measured at 100 gf load for 10 seconds where indents were 100 µm apart. A Zwick/Roel ZHVµ Indentec hardness machine was utilized for microhardness measurements. The wear behaviour of the laser cladding fabricated coating was tested using a pinon-disk tribology (TRT) (Anton Paar Germany GmbH, Ostfildern, Germany) apparatus. Ti-Si binary alloys and Ti-6Al-4V alloy were tested for wear resistance using a pin-on-disk technique. The abrading ball was a 6.00 mm Cr_2C_2(NCr) sliding partner abrading against the titanium alloy. The loading force was 10N where the static Cr_2C_2(NCr) ball was operated at 7.83 cm/s to produce circular tracks due to the rotational motion.

3. Results and Discussion

3.1. SEM Characterization

Figure 1 illustrates the microstructural orientation of Ti-Si coatings deposited at power of 2.1 kW and laser scanning speed of 1.2 m/min, 1.6 m/min and 2.0 m/min respectively. The exhibited microstructure indicated a transformation with an increase in laser scanning speed to a more refinined microstructure. According to [14], an increase in laser scanning speed favours rapid solidification which [15] associates with microstructural refinement.

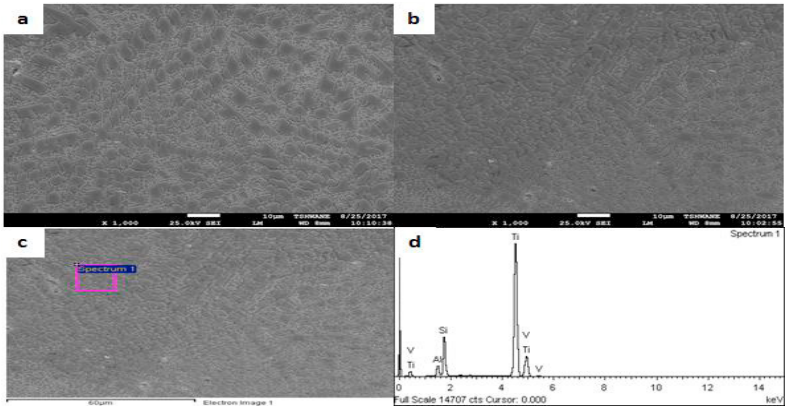

Figure 1: a) SEM Characterisation of Ti-Si Deposited at 2.1kW and 1.2 m/min; b) Deposited at 2.1kW and 1.6 m/min; c) EDS Scanned area of Ti-Si Deposited at 2.1kW and 1.6 m/min; d) EDS Spectra of Ti-Si Deposited at 2.1kW and 1.6 m/min

The coating is found to be made up of club-like aquiaxed grains at 1.2 m/min and localised irregular crystal colonies outside of the filed of the equaiaxed grains. An increase in laser scanning speed by 33.33% to 1.6 m/min is seen to result in a decrease in the the size grains structures where the high rate of solidification can be said to favour multiple nuclei and formation of new nucleation sites. A further increase in laser scanning speed evidently led to a further decrease in grain size. This further refinement as a consequence of rapid solidification favours surface properties such as microhardness. According to [16], laser scanning speed greatly affects the nature of the resultant microstructure.

3.2. XRD Analysis

Figure 2 illustrates the Ti-Si phases identified by XRD analysis at the varying experimental laser scanning speeds employed in the fabrication of the alloy coatings. The nature of the morphology greatly determines the properties of the coating such that, a coating identified to possess superior phases would more likely exhibit excellent properties.

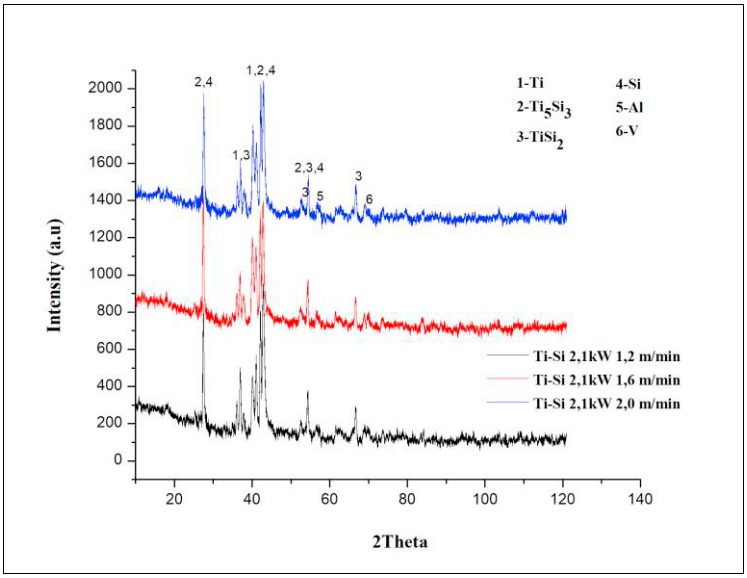

Figure 2: Phase Identification on Ti-Si Binary Alloy Coatings

The coatings are seen to contain Ti_5Si_3 and $TiSi_2$ intermetallic phases. Intermetallic phases are known for their superior properties particularly Ti_5Si_3 which has high hardness and high oxidation resistance [6]. However, [17] reported Ti_5Si_3 to be brittle at room temperature which necessitates the presence of other phases that possess low hardness such as α-Ti. Ti and Si act as support matrix within which intermetallic phases precipitate. Silicon matrix however also contributes to increasing the hardness property.

3.3. Microhardness and Clad Height Studies

Figure 3(a) and Figure 3(a) displays the microhardness profiling and clad height on Ti-Si laser clad coatings on Ti-6Al-4V alloy respectively. It can be observed that the coating surface displayed relatively higher microhardness compared to the substrate material. The microhardness of the substrate alloy was measured at 342.3 $HV_{0.1}$.The improved morphology and microstructure were vital in achieving high microhardness due to the precipitation of Ti_5Si_3 and the subsequent microstructural refinement with an increase in laser scanning speed. As a result, it can be observed on the profiling trend that the coating developed at 2.0 m/min achieved the highest average microhardness across the coating followed by coating developed at 1.6 m/min.

Coatings developed at 1.2 m/min achieved the lowest microhardness reading coupled with low microstructural homogeneity. However, the troughing and peaking of the microhardness values for all the coatings can be attributed to the presence of elongated and refined grains. This inhomogeneity encourages a variation in the microhardness measurements. The coatings produced on Ti-6Al-4V was observed to increase with an increase in laser scanning speed where 836 $HV_{0.1}$ (1.2 m/min) < 891 $HV_{0.1}$ (1.6 m/min), 836 $HV_{0.1}$ (1.2 m/min) < 905 $HV_{0.1}$ (2.0 m/min) and 891 $HV_{0.1}$ (1.6 m/min) < 905 $HV_{0.1}$ (2.0 m/min). This represents 2.4, 2.6, 2.64 times increase in microhardness

across the coatings against 342.3 $HV_{0.1}$ for 1.2 m/min, 1.6 m/min and 2.0 m/min respectively.

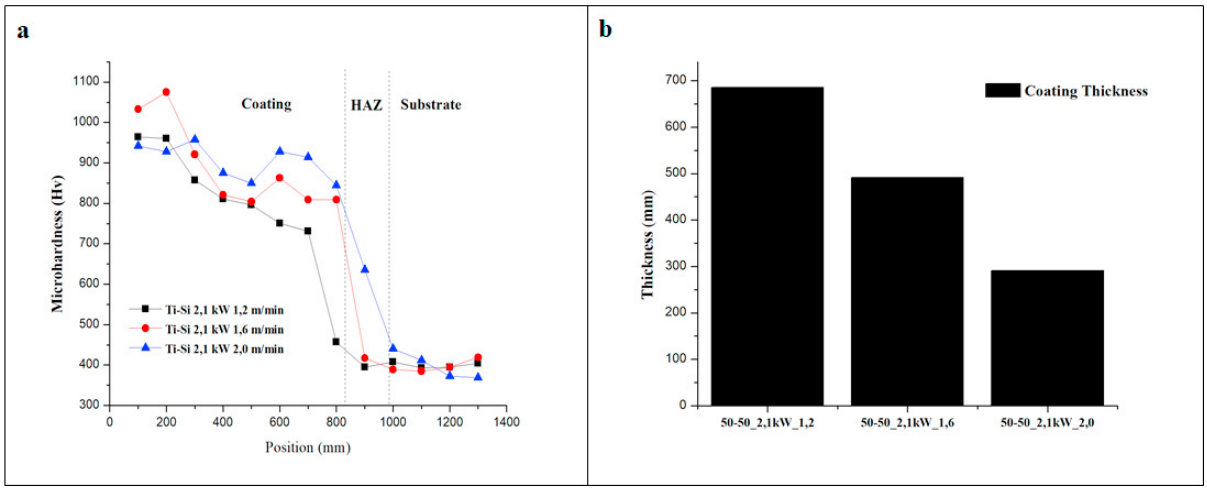

Figure 3: a) Microhardness Profiling of Ti-Si Alloy Coatings; b) Clad Height Profiling of Ti-Si Alloy Coatings

Figure 3b represents the clad height of the laser clad coating of Ti-Si. It can be seen that, the plot represents an inverse relation for laser scanning speed and clad height. At higher laser scanning speed of 1.2 m/min, it can be seen that the clad height is the highest. According to [18], under lower laser scanning speeds, the action of the laser beam on the surface is prolonged. The decrease in clad height was measured at 685.8 µm, 491.5 µm and 291.5 µm for 1.2 m/min, 1.6 m/min and 2.0 m/min respectively.

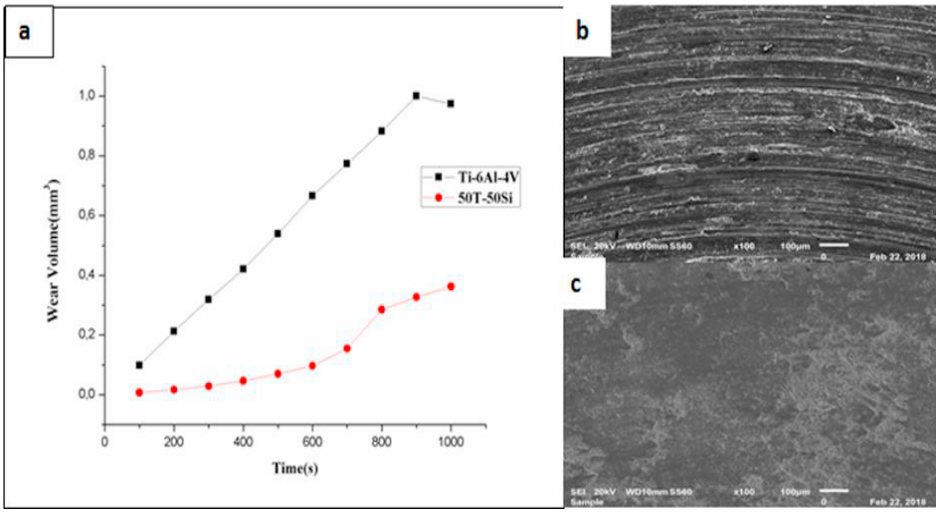

Figure 4: a) Wear Volume of Ti-6Al-4V Alloy and Ti-Si Alloy Coating; b) Wear Scar on Ti-6Al-4V Alloy Surface; c) Wear Scar on Ti-Si Alloy Surface

Figure 4 displays the Wear volume and SEM micrographs of the laser clad coatings scar. In comparison to the substrate material which displayed severe dilapidation and aggravated plastic deformation, the coatings reveal evident of reduced damage. The low wear volume can be attributed to the high hardness recorded in figure 3(a) which was a result of the presence of Ti_3Si_5 which possesses high hardness [19]. The compact and uniform laser fabricated microstructure contributed to the uniform scar which revealed little material removal. This is affirmed by reduced presence of transferred debris as opposed to the substrate material which reveals that adhesive wear resulted

in debris accumulation and transfer. Further, the debris resulted in secondary material removal by acting as friction bodies.

4. Conclusion

Compact Ti-Si binary alloy coatings were successfully developed on To-6Al-4V alloy via laser cladding at set parameters (Power-2.1 kW; laser scanning speed-1.2, 1.6, 2.0 m/min). The coatings were defect free with compact microstructure characterized by refined grains and clusters of elongated crystals. Ti, Si, Ti_5Si_3 and $TiSi_2$ were found to be present in the coatings. Coating hardness increase was in the order 2.44, 2.6 and 2.64 for 1.2 m/min, 1.6 m/min and 2.0 m/min respectively. The increase in laser scanning speed was found to decrease the clad height in the order 685.8, 491.4 and 291.5 for 1.2 m/min, 1.6 m/min and 2.0 m/min respectively. Wear test indicated that the coating had an improved wear resistance by evidence of little material removal exhibited compared to the substrate which was dilapidated by severe adhesive wear aggravated by plastic deformation.

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References

[1] Y. Fu, A.W. Batchelor, Y. Wang, K.A. Khor, Wear. 217 (1998) 132-139
[2] O. Okuno, H. Hamanaka, Dent. J. 26 (1989) 101-104.
[3] Z. Jiang, X. Dai, H. Middleton, Mater. Sci. Tech. B176 (2011) 79-86
[4] H. Dong, X.Y. Li, T. Bell, J. Alloy. Comp. 283 (1-2) (1999) 231-240
[5] S. Yin, B. Huang, Z. Yin, Mater. Des. A280 (2000) 204-207
[6] K. Kishida, M, Fujiwara, H. Adachi, K. Tanaka, H. Inui, Acta. Mater. 58(3) 846-*857*
[7] Z.H. Tang, J.J. Williams, A.J. Thom, M. Aknic. Intermetallics. 16 (2008) 1118-1124
[8] M. Alhammad, S. Esmaeili, E. Toyserkani, Surf. Coat. Tech. 203 (2008) 1-8
[9] F. Weng, H, Yu, J. Liu, C. Chen, J. Dai. Z. Zhao, Optic. Laser. Tech. 92 (2017) 156-162
[10] Z. Jian, W. Wenni, Z. Longzhi, Hot. Work. Tech. 42 (2013) 131-135
[11] D.S. Gnanamithu., E.A. Metzbower (ed,) Proc. Conf. on the Application of Lasers in Materials Processing, Washington, DC,1979 p. 177.
[12] G.P. Dinda, J. Shin, J. Mazumder, Acta. Biomater. 5(5) (2009) 1821-1830.
[13] Y. Sun, M. Hao, Opt. Laser. Eng. 50 (2012) 985–995.
[14] Y. Yang, G. Guo, J. Li, Surf. Coat. Tech. 219 (2013) 1-7
[15] F.X. Huang, Z.H. Jiang, X.M. Liu, J.S. Lian, L. Chen, ISIJ.Int. 51(3) (2011) 441-447
[16] S. Li, H. Hassanin, M.M. Attallah, N.J.E. Adkins, K. Essa, Acta Mater. 105 (2016) 75-83
[17] J. Dutta Majumdar, B.L. Mordike, L. Manna, Wear. 242 (2000) 18–27.
[18] R. Li, Y. Jin, Z. Li, Y. Zhu, M. Wu, Surf. Coat. Tech. 259 (2014) 725-731
[19] Y.Z. Zhan, Z.W. Yu, C.H. Li, Z. Sun, Y.F. Fun, X.F. Xu, Y. Wang, Y.H. Zhuang, J. Alloy. Comp. 461 (2008) 128-131