Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 36 (2012) 349 – 354

Procedia Engineering

www.elsevier.com/locate/procedia

IUMRS-ICA 2011

Study of In-situ Synthesis TiCp/Ti Composite Coating on Alloy Ti6Al4V by TIG Cladding

Rongjuan Yang[a,]*, Zongde Liu[a,b], Guang Yang[a], Yongtian Wang[a]

[a]*Key Laboratory of Condition Monitoring and Control for Power Plant Equipment of Ministry of Education, North China Electric Power University, Beijing 102206,China*

[b]*Suzhou Research Institute of North China Electric Power University, NO.188, Renai Road, Xietang area, Suzhou 215123,China*

Abstract

The composite coating reinforced by TiC particle was in-situ produced on the surface of TC4 Ti alloy by means of TIG cladding technique with powder-filled cored wires (Ti-strip to wrap powder of Ti, C and Al). The microstructure and composition modifications in the surface layer were carefully investigated by using SEM, EDX and XRD. The results showed that a good metallurgical bond between the coating and the substrate can be achieved; the coating is uniform, dense, continuous and almost defect-free; the particles by in-situ synthesis are dispersedly distributed in the cladded coating; TiC has there different shapes: dendritic shape, shore-bar and equiaxed or near-equiaxed shape. The microhardness of coating was irregular and the maximum value was approximately 1300 HV0.5, about 6.5 times of the initial one.

Keywords: Micro-hardness; titanium matrix composites (TMCs); TIG cladding; in situ formation; TiC

1. Introduction

Titanium and its alloys are extensively used in aeronautical, marine and chemical industries owing to their specific properties such as high strength, excellent corrosion, and oxidation and high-temperature resistance. Alternatively, their low hardness and poor abrasion resistance limits their further applications [1-3]. So, surface modification of titanium and its alloys is a promising work in enlarging their application scope. To improve the hardness and to increase the service lifetime of TC4 at high temperatures, a surface coating process has been carried out using various surface treatment techniques [3-6]. The cladding coatings by powder-filled core wires possess high hardness, high wear resistant,

* Corresponding author. Tel.: +86-10-6177-2291; Fax: +86-10-6177-2812.
E-mail address:yrj-3121@ncepu.edu.cn.

1877-7058 © 2012 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2012.03.051

resistant to corrosion, antioxidant, anti-erosion and other performance.

TIG cladding technology features easy operation, stable function, safety and stability energy concentration non-oxidation process and so on other advantages [7]. So, high quality of clad layer can be achieved by TIG cladding. TiC, being used as cladding materials, are now invoking more and more interests because of their many premium properties, such as good thermal and chemical stabilities, excellent compatibility on the interface, and high melting points, hardness and Young's modulus [8]. Considering the advantages mentioned above, we modified the titanium surface with Ti-base cored wires by TIG, which is simpler and less expensive.

2. Experimental details

2.1 Sample preparation and TIG clad treatment

Ti-base cored wires were prepared by using Ti-strip to wrap powder of Ti, C and Al. Commercial powders of aluminum (purity > 99.5%), titanium (purity > 99.5%) and carbon (purity > 99.5%) were used for experiments. The particle sizes of all the powders were within 80–200 μm. The powder were blended with each other according to certain proportions, ball milled at air atmosphere for 60 h, dried in a drying oven for 1h, and packed to cored wires of 2 mm diameter using the Ti foil of 50 μm thickness. The substrate material is Ti6Al4V alloy with (α+β) dual phase micro-structure, its nominal chemical composition is as follows: 5.5～6.75% Al, 3.5～4.5% V and balance Ti (mass fraction). The samples for cladding treatment were cut into small coupons (20mm×10mm×6mm) from a 6 mm-thick sheet.

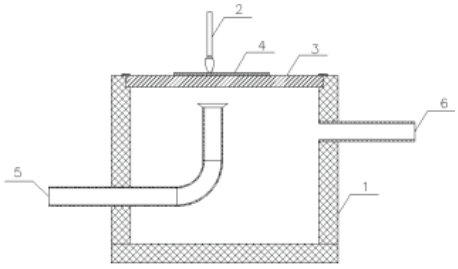

Fig.1. The schematic picture of TIG cladding with auxiliary cooling system(1) cooling water system; (2) argon arc soldering gun ; (3) TC4 plates; (4) cored wire for cladding; (5) cooling water inlet; (6) cooling water outlet.

The samples were ground and polished with sand papers, and ultrasonically cleaned in acetone prior to the TIG cladding treatments. The sample was then placed self-made cooling equipment, as illustrated schematically in Fig.1, which was promoted the cooling rate of cladding alloy in molten pool and decrease the dilution of cladding alloy from the substrate metals during the cladding-like processing. A self-made TIG cladding system which was developed by the Department of Materials Science and Engineering in North China Electric Power University was adopted for the cladding-like processing. The optimal processing parameters are the operation current (140 A), electric voltage (20 V) and remelting rate (5 mm/s), respectively. In addition, pure argon (99.99%) at 18 L/min was used as plasma gas and shielding gas so as to prevent the sample and powder mixture from oxidation during the cladding processing.

2.2 Coating analysis

In order to characterize the TIG cladding coatings as a function of the welding parameters

metallographic specimen preparation procedures were performed on cross-sectional samples of the treated alloys. The phase present on the surface of the modified sample identification were made by X-ray diffraction (XRD) analysis using the Cu Kα radiation. The microstructure of the treated samples was observed from cross section by using optical microscopy (OM) and scanning electron microscopy (SEM) equipped with an electron dispersion X-ray spectroscopy (EDX). Vickers hardness testing was carried out with a load of 500 g for 15s.

3. Results and discussion

3.1 X-ray diffraction phase analysis

Fig. 2(a) shows XRD patterns recorded from the untreated and treated samples. From the results it is very clear that the phases in the composites coatings are composed of Ti and TiC phases. Theoretically there should exist Al in the composites due to the cored wires including of Al powder, but XRD analysis does not show the occurrence of Al. This is because the mass fraction of Al power is only 7.2 wt. % in the composites and seems to distribute only between the TiC dendrites. In other words, Al stays mainly in the α-Ti. The remaining amount of Al is too small to be detected by XRD analysis. The result of the X-ray diffraction analysis confirms that the titanium matrix composites coatings reinforced with TiC can be produced by TIG cladding technique using the self-made Ti-base cored wires.

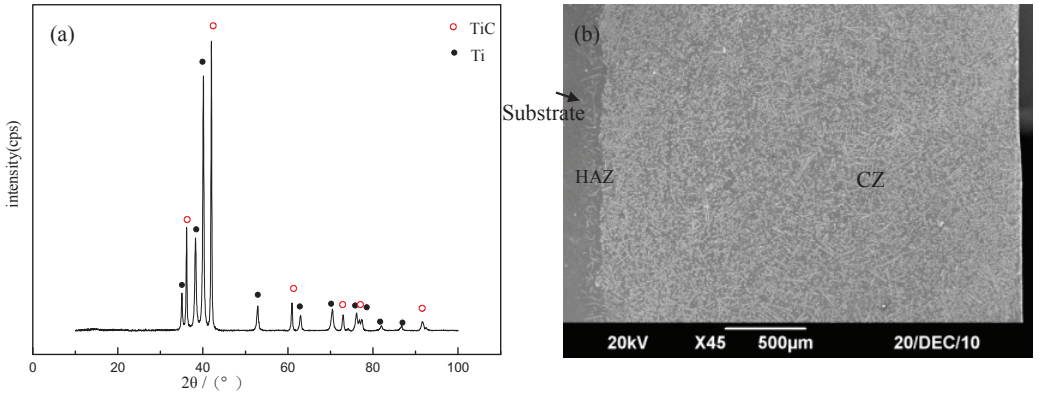

Fig.2 (a) X-Ray diffraction pattern of in situ synthesized TiC/Ti composites; (b) Cross-sectional SEM morphology of in situ synthesized TiC/Ti composites.

3.2 Microstructure of laser clad coatings

Fig.2 (b) and Fig.3 shows SEM and OM images illustrating the aspects of the TIG cladding layer in a cross sectional view. Fig. 2(b) is a macrograph of TIG cladding track transverse cross-section. It is obvious that the ceramic compounds layer is continuous, free from pores and cracks, closely packed, with a thickness of about 2.7 mm. The appropriate values of parameters have been chosen to obtain the most homogeneous surface. Due to melting, liquid state mixing followed by rapid solidification and cooling, a layer with graded microstructures and compositions formed. According to micro-structure and color difference, the cross sectional view can be divided into 4 regions: clad zone (CZ), heat affected zone of

the substrate (HAZ), and substrate. TiC with kinds of morphologies can be attained with different zones. All of these differences are mainly due to the influence of the temperature gradient and solidification speed. The clad zone is formed of irregular TiC particles and acicular phase dispersed in Ti matrix. The bonding zone with thickness of approximately 70–80 μm possesses a microstructure of small dendrites and short-bar shape and the heat affected zone is acicular martensite. Fig.3a–d shows the OM micrographs of typical cross-sections of the dense TiC–Ti cermets prepared by the TIG technology. It can be seen clearly that the dark contrast crystal particles with dendrite, short-bar shape and spherical shape were relatively completely and uniformly dissolved into throughout the coating during melting. The interfacial bonding of TiC and Ti is distinct and good as a result of the TiC crystal particles are formed in-situ in the molten pool.

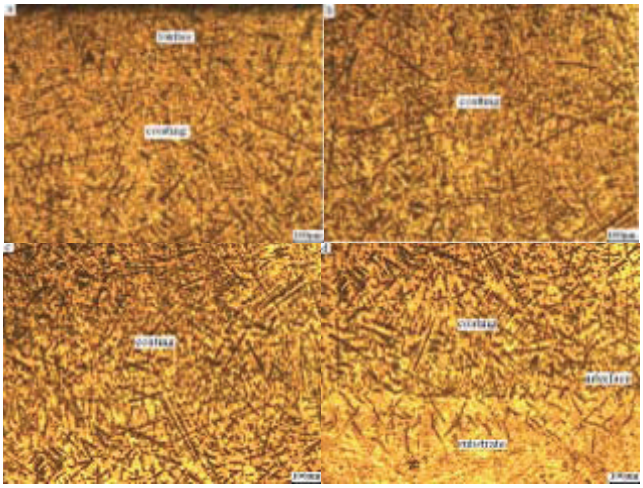

Fig.3. Optical micrographs of in situ synthesized TiC/Ti composites.

Fig.4 is cross-section high magnification SEM image of the TIG cladded coatings in which the depth (from the surface of the coating to the substrate) is equal to 0, 1500 and 2800 μm, respectively. It is noted that some particles are tightly bonded or grown together (gray area) while some are isolated and the particles are of a spherical shape. The EDS analysis results on the gray area and the isolated particles show that there are no differences in chemical composition. They are all composed of TiC which is in accordance with the XRD result. The inter-dendritic areas were filled with fine α′ phase which is caused by α-Ti transferred into α′-Ti during cooling lamellae enrich in Al. For the coating in which depth is equal to 0, as shown in Fig.4(a), the size of the in-situ formed TiC particles (dark phase) is bigger, and the largest size is more than 35 μm due to the grains accumulate and grow up. For the layer in which depth is equal to 1500 μm, as we can see in Fig.4(b), it can be observed clearly that the in-situ prepared TiC particles is dendrites and short-bar shape and smaller with an average size of less than 10 μm. For the layer in which depth is equal to 2800μm, the microstructure of which is shown in Fig.4(c), only a little spheroidal shape crystalline grains embedded in the dark substrate. Even more important, the crystalline grains are much smaller and regular （about 1-3 μm） than in the previous zones and distributes more homogeneously. In conclusion, multistage crystallization is existed in the TIG cladding process. In addition, the liquid metals Ti (grey) surrounding the TiC grains increases and leads to an increase in diffusion path and decreases the driving force for grain growth of TiC and discourages the coalescence of TiC grains to form larger grains. Thus, with the increase in the depth, the TiC particles size will decrease

gradually.

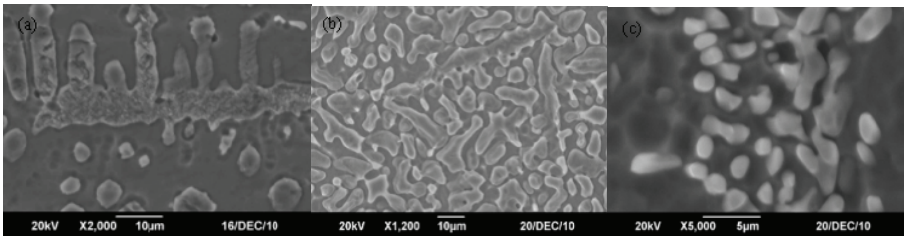

Fig.4. SEM images of TIG cladding layer at different zones (a, b, c) (a) Top surface; (b) Subsurface at about 1500 μm; (c) Subsurface at melt/substrate interface.

3.3 Hardness

Fig.5 shows the micro-hardness of the TiC–Ti cermets coating. As seen from Fig.5, the composite coating presents higher micro-hardness. The improvement in hardness is due to the in-situ synthesis of TiC and its homogenous distribution in the cladding layer. The micro-hardness of the coating is decreased gradually from the coating through the interface to the TC4 substrate. In addition, the hardness of the top surface of the composite coating is relatively lower than that of the central region of the coating. This is mainly attributed to the lower volume fraction and bigger size of TiC dendrites on the top surface of the coating as TiC is very hard and plays the major role for the increased hardness [6, 9]. As the document [9] mentioned, the hardness of the TiC–Ti cermets coating is determined both by the volume fraction and the size of TiC dendrites. The micro-hardness of coatings increased with increased the TiC volume fraction. In contrast, it decreased with increased the size of TiC dendrites. Mainly due to the reduced TiC volume fraction with increasing depth, the hardness decreases with increasing depth in the coating with a maximum value of HV1000, about 5 times of the initial one. It can be seen that the hardness is increased significantly after TIG cladding.

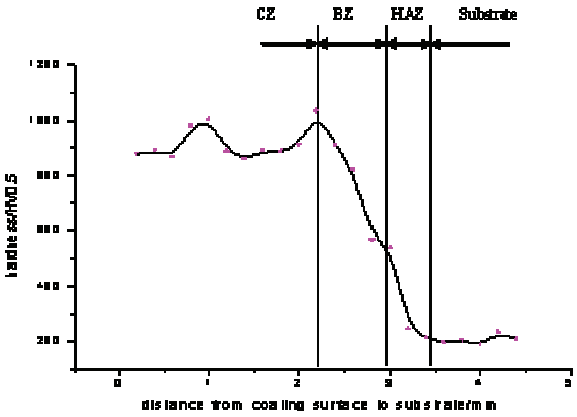

Fig.5. Microhardness profile on cross-section of in situ synthesized TiC/Ti composites.

4. Conclusions

- 1. TiC can be in-situ formed on the surface of Ti-6Al-4V alloy successfully by self-made TIG cladding with powder-filled cored wires because TIG the supplied energy is sufficient to excite the reaction among the initial products.
- 2. The XRD results showed that the compounds were consisted of TiC phase and Ti phase, while Al stays mainly in the α-Ti.
- 3. The TiC particles size will decrease gradually with the increase in the depth. In addition, coarsening dendrites in the surface of the coating; smaller dendrites and short-bar shape in the middle of the coating and relatively smaller spheroidal shape crystalline grains in the bottom of the coating.
- 4. The micro-hardness of the coatings decreased gradually with the increase in the depth and improved about 5 times of the initial one. According to the micro-structure analysis results mentioned above, many TiC hard particles were dispersed in the matrix, which significantly enhance the hardness of the clad coatings.

Acknowledgements

This project was supported by the Scientific and Technological Achievements Transformation and Industrialization of Beijing Municipal Education Commission, the Suzhou Municipal Science and Technology Plan Project (Grant No.SYG201002), the National Natural Science Foundation of China (Grant No.51101056) and National Science & Technology Pillar Program (Grant No.2011BEA12B03).

References

[1] HAGER C H J, SANDERS J H, SHARMA S. *Wear*, 2008; **265**(3/4): 439−451.

[2] Casalino, G., Curcio, F., Memola, F., Minutolo, C., *Mater. Process. Technol*. 2005; **167**: 422–428.

[3] Wang, S.H., Wei, M.D., Tsay, L.W., *Mater. Lett*. 2003; 57: 1815-1823.

[4] VARIOLA F, YI J H, RICHERT L, JWUEST J D, ROSEI F, NANCI A. *Biomaterials*, 2008; **29**(10): 1285-1298.

[5] SILVA M M, UEDA M, PICHON L, REUTHER H, LEPIENSKI CM., *Nuclear Instruments and Methods in Physics Research B*, 2007; **257**(1/2): 722-726.

[6] PANG W, MAN H C, YUE T M. Laser surface coating of Mo–WC metal matrix composite on Ti6Al4V alloy *[J]*. *Materials Science and Engineering A*, 2005; **390**(1/2): 144-153.

[7] Wu Xiaolei, Chen Guangnan, *Acta Metlllurgical Sinica,* 1998; **34** (12): 1284-1288

[8] Yamamoto R M, Allen K L, Allmon R W, et al. *A solid state laser for the battlefield [R]*. *Lawrence Livermore National Laboratory, 25th Army Science Conference, UCRL-CONF*-225230, 2006.

[9] YANG Yu-ling, ZHANG Duo, YAN Wei, ZHENG Yi-ran. *Optics and Lasers in Engineering*, 2010; **48**(1): 119-124.