Remanufacturing of Aero-engine Components by Laser Cladding

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Abstract—This paper presents a pulsed laser cladding of TiN-Ti composites used for aero-engine overhaul. In order to analysis the practicability in application, the microstructures, microhardness and other performances of the composite coating were investigated. The results show that the interface between the remanufacturing zone and the substrate is metallurgical bond. The remanufacturing zone is mainly composed of TiN phase and alpha martensite. TiN phases distribute discretely in the remanufacturing coatings and display two typical morphologies, namely the coarse particle TiN and the dendrite TiN. The difference of formation mechanism is the reason why TiN phases display two different morphologies. Compared with the substrate, the repair coatings show better performances on microhardness and wear resistance in same condition. The different performances between remanufacturing coatings and substrate can be mainly attributed to the reinforcement of different TiN phase introduced into the composite coatings. The results above indicate that, it is feasible to repair the aero-engine components by laser cladding of TiN-Ti composites.

Keywords- laser cladding; remanufacturing; aero-engine; titanium alloy; wear resistance

I. INTRODUCTION

Titanium alloy, which possess the advantages of low density and high weight to strength ratio [1,2], has been widely used in aviation industry as various structural members [3,4]. In aero-engine, there are many structural members made of titanium alloy, such as the blades, wheels and dual hinges. During hundred hours of services, some of them suffer heavy erosion, which increases the risks of the aircraft [5]. Furthermore, these components are usually expensive for the strict standard of quality [6]. So, to develop a method that can repair the failure components becomes meaningful [7-10]. Traditional repair methods usually cause large heat-affected zone (HAZ) and visible deformation [2] and are unsuitable for the repair application on those high accuracy components, which impels researchers to explore novelty remanufacturing technologies in this area [1,5].

Laser cladding is a kind of surface modification technique. In recent years, Laser cladding is widely employed to fabricate various coatings with improved wear resistance [11-13], high temperature oxidation resistance [14,15] and other performances on titanium and its alloys. In these researches, apart from laser cladding process parameters, material selection is vital to obtain the improved properties mentioned above.

In this paper, a TiN-Ti pulse laser cladding is successfully applied to the remanufacturing of aero-engine components. The microstructures, microhardness and wear resistance of the repair coating are studied. The results may lead to an increasing interest in the investigation of increasing service life and decreasing cost in aero-engine overhaul, which will provide a guideline for their further industrial application.

II. EXPERIMENTAL DETAIL

First, the eroded surface of the failure zones was cleaned by a sander to remove the damaged layer. Then, the Ti-N pre-nitriding precursor, which was mixed from Ti-powder and 10% pre-nitriding powder, was preplaced on the cleaned surface. With argon gas to protect the irradiation zone, a JQM-1GXY-400 type Nd:YAG pulse laser machine was used for laser cladding (Fig .1). Laser cladding was carried out at the parameters as follows: current 160 A, pulse width 12 ms, frequency 4 Hz, overlapping rate 75%, and laser irradiation spot diameter 1.4 mm. The average output power was ~ 400 W and energy for each single pulse was ~5 J.

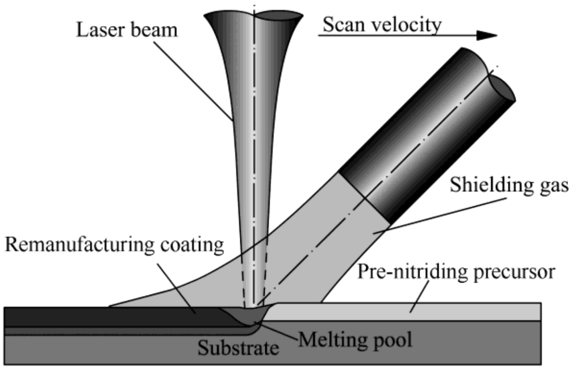


Figure 1. Diagrammatic sketch of pulse laser cladding.

Detailed SEM examination was performed on the surfaces and cross-sections with a Philips XL-400 type electron scanning microscope. The specimens for cross-sectional morphology observation were prepared using standard metallographic techniques and etched with a 0.5% HF. A D-max 2500PC X-ray diffraction was employed for XRD analysis. The HX-1 type microhardness tester was used for the hardness test with the load of 50 g and load time of 15 s.

Wear tests were processed by an WTM-2E type abrasive wear testing machine with a test period of 720 min. The loads used were 500 g. The rotate speed was 600r/min. Before and after each test period, the specimen was degreased, rinsed, dried, and weighed by using an analytical balance with an accuracy of 0.1 mg.

III. RESULTS AND DISCUSSION

A. The Remanufacturing of the Failure Components

Two kind of typical structural components in aero-engine, i.e. the wheels (as shown in Fig .2a) and the blades (as shown in Fig .2b), were used for experimentation.

For the titanium wheel, the cicatricial failure zone is located at the tip segment, which is shown in Fig .2(a). Titanium wheel were made of TC6 alloy with a nominal composition of Ti-6Al-2.5Mo-1.5Cr-0.5Fe-0.3Si. The depth of the failure cicatrice is about 200~500 μm, and the max width of the eroded zone is about 2 mm.

Fig .2(b) displays the typical failure blade with a damage on the damping shoulder. This blade was made of TC4 alloy with a nominal composition of Ti-6Al-4V. The size of worn zone was about 2 mm × 8 mm, and the depth of the failure cicatrice was about ~500 μm.

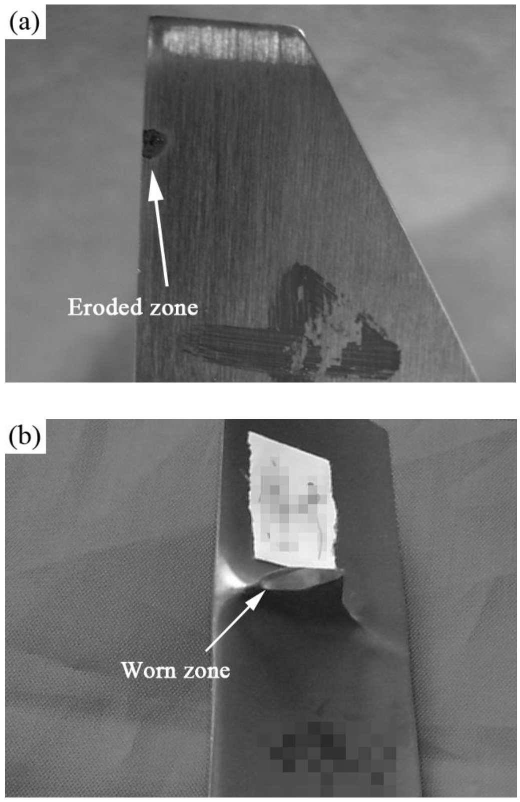
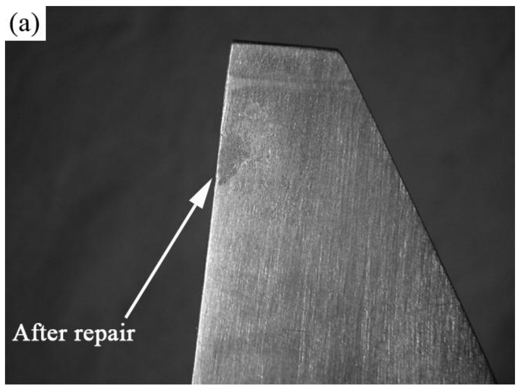


Figure 2. The failure wheel tip(a) and the blade damping shoulder (b).

The eroded tips of wheels remanufactured by pulse laser cladding is displayed in Fig .3(a). For the worn blades, the damping shoulder after remanufacturing is shown in Fig .3(b). It is visible that the repaired surfaces are shiny and neatness. The sample shown in Fig .3(a), i.e. the wheel tip sample, is selected for investigating the microstructures, coating-substrate interface bonding and performances further. The cross-sectional morphology of the wheel tip sample, which is illustrated in Fig .4, indicates that the remanufacturing coating is compact and uniform without any crack, pin hole or other defects. The interface between the repaired zone and substrate is metallurgical bond. In addition, the deformation of the repair zone is also negligible, which can be mainly attributed to the patent pre-nitriding and pre-placing method of alloy powder and the thermal stress control during laser irradiating [2].



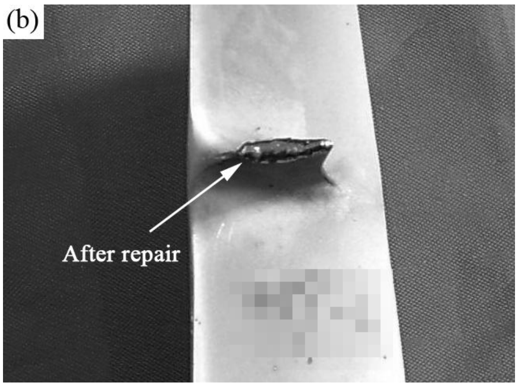


Figure 3. The wheel tip (a) and blade damping shoulder (b) after remanufacturing.

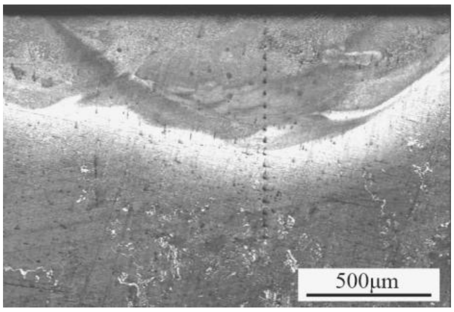


Figure 4. The cross-section of remanufacturing zone.

B. Microstructure

The typical microstructures of the remanufacturing zone are shown in Fig .5. XRD results indicate that the coating is mainly composed of TiN and α′ martensite. Fig .5(a) displays the TiN phases in the composites. The TiN displays two typical morphologies, namely the coarse particle TiN and the dendrite TiN.

The coarse particle TiN is characterized by the ball-like shape, while the margin is a transition zone from TiN to the matrix of α′ martensite. The dimensions of the coarse particle TiN are usually in the range of 10-50 μm, which implies that this type TiN are not synthesized from molten pool reaction since the TiN phase obtained by reaction usually smaller than the results shown in Fig .5(a) [1]. Based on the characters and analysis above, it is can be inferred that the coarse particle TiN are the residual of the large pre-nitriding particles.

On the contrary, the dendrite TiN is characterized by dendrite-like morphologies. Dendrite morphologies of TiN are the typical results of crystal growth in molten pool [2], which imply that the dendrite TiN are the in situ syntheses TiN in molten pool reaction.

Fig .5(b) display the morphologies of α′ martensite with the typical needle-like characteristics.

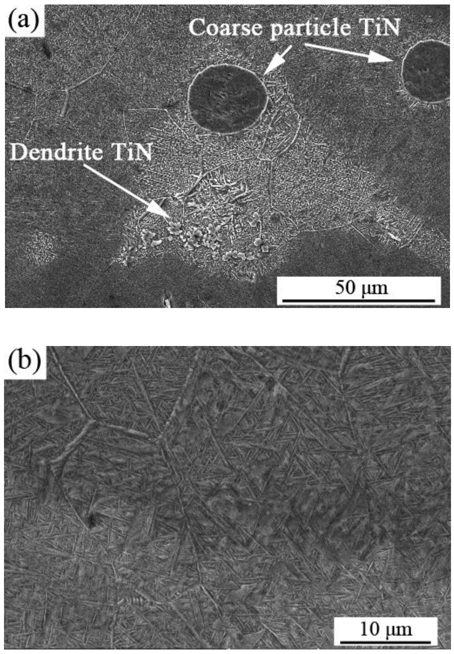


Figure 5. The microstructures of the 10% TiN remanufacturing coating formed by pulse laser cladding: (a) the TiN phase in the coating and (b) the typical microstructure of α′ martensite.

C. Microhardness and Wear Resistance Test

Fig .6 shows the comparison of hardness between Ti-N remanufacturing zone and the substrate. It is evident that the average hardness of the remanufacturing zone is ~500 HV and is higher than that of the substrate (about 320 HV). The improvement of microhardness stems from the formation of TiN particles and TiN dendrites located in the remanufacturing coatings. Laser cladding processes transform the initial pre-nitriding TiN phase into the particle and dendrite TiN, which results in hardening effects obviously.

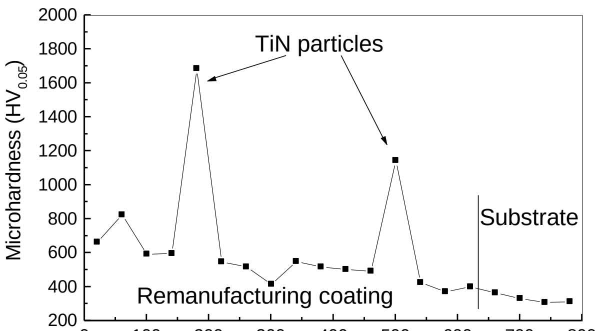


Figure 6. the comparison of microhardness between Ti-N remanufacturing coating and the substrate.

As can be seen in Fig .6, there are some high hardness points in remanufacturing coatings. The hardness value of these points is displayed in Table I. It is evident that the hardness fluctuation of Ti-N composite coating can be attributed to the coarse TiN particles since the hardness of TiN is extremely high with a value of ~ 1990 HV.

TABLE I. THE HIGH HARDNESS POINTS AND THE HARDNESS VALUE

Serial Number of Hardness Points	Hardness Value and Position	
	Hardness Value(HV0.05)	*Remarks*
2	822.5	
5	1683.6	On coarse particle
13	1141.6	On coarse particle

The mass losses of the Ti-N remanufacturing coatings and the substrate in wear tests are illustrated in Fig 7(a) and Fig .7(b). Compared with the substrate, the remanufacturing coating shows better wear resistance since the mass loss in 720 min test is only 19.2 mg and is less than that of the substrate (62.6 mg).

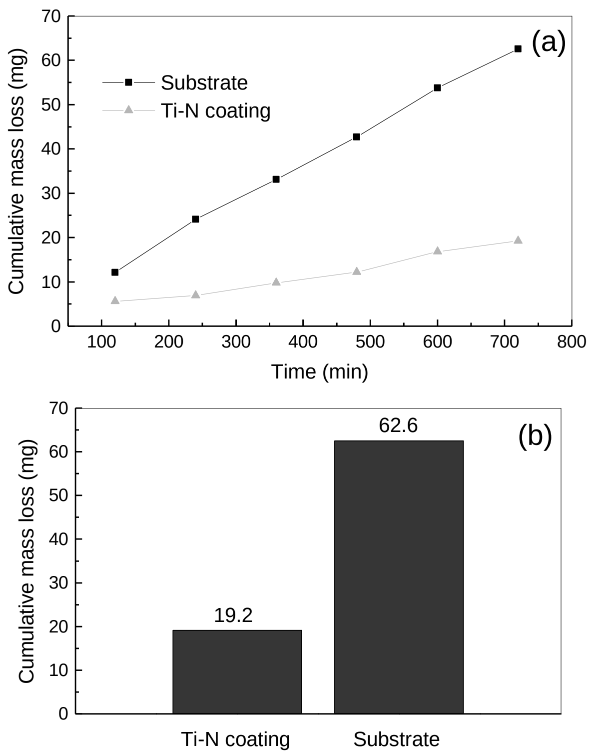


Figure 7. Mass losses of the remanufacturing coatings for 720 min tests: (a) Curves of mass loss vs. time and (b) Comparision of cumulative mass loss (mg).

IV. CONCLUSION

1. By pulse laser cladding, the failure wheel tips and blade damping shoulder can be successfully repaired without any pinhole, crack or other defects. The hardness and mass losses of the remanufacturing coatings are better than the substrate.

2. The Ti-N pre-nitriding remanufacturing coating is mainly composed of TiN and α′ martensite. The improvement on performances can be mainly attributed to the N introduced by the pre-nitriding method. As a result, two typical morphologies of TiN, namely the particle morphology and the dendrite morphology, are obtained.

3. It is feasible to repair the failure titanium alloy components by "pre-nitriding + pulse laser cladding" method.

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REFERENCES

[1] S. Katayama, Handbook of Laser Welding Technologies, Cambridge: Woodhead Publishing Limited, 2013.

[2] H.S. Dong, Surface Engineering of Light Alloys, Cambridge: Woodhead Publishing Limited, 2014.

[3] Y.Y. Fu, Y.Q. Song, S.X. J.M. Hui, Xu. "Research and application of typical aerospace titanium alloys". Chinese Journal of Rare Metals, Volume 30, December 2006, pp.850-856.

[4] X.N. Mao, Y.Q. Zhao, G.J. Yang. "Development situation of the overseas titanium alloys used for aircraft engine". Rare Metals Letters, Volume 26, May 2007, pp.1-7.

[5] D. Fratila, "8.09 - Environmentally friendly manufacturing processes in the context of transition to sustainable production". Comprehensive Materials Processing, Volume 8, 2014, pp.163-175.

[6] E. Asmatulu, J. Twomey, M. Overcash, "Evaluation of recycling efforts of aircraft companies in wichita". Resources, Conservation and Recycling, Volume 80, November 2013, pp.36-45.

[7] H. Singh, P.K. Jain, "Remanufacturing with ECH – a concept. Procedia Engineering", Volume 69, 2014, pp.1100-1104.

[8] Z. Li, X.J. Tian, H.B. Tang, H.M. Wang, "Low cycle fatigue behavior of laser melting deposited TC18 titanium alloy", Transactions of Nonferrous Metals Society of China, Volume 23, September 2013, pp.2591-2597.

[9] Y.Y. Zhu, D. Liu, X.J. Tian, H.B. Tang, H.M. Wang. "Characterization of microstructure and mechanical properties of laser melting deposited Ti–6.5Al–3.5Mo–1.5Zr–0.3Si titanium alloy", Materials & Design, Volume 56, April 2014, pp.445-453.

[10] C.M. Liu, X.J. Tian, H.M. Wang, D. Liu, "Obtaining bimodal microstructure in laser melting deposited Ti–5Al–5Mo–5V–1Cr–1Fe near β titanium alloy", Materials Science and Engineering: A, Volume 609, July 2014, pp.177-184.

[11] J.J. Candel, V. Amigó, J.A. Ramos, D. Busquets, "Sliding wear resistance of TiCp reinforced titanium composite coating produced by laser cladding", Surface and Coatings Technology, Volume 204, July 2010, pp. 3161–3166.

[12] L.F. Cai, Y.Z. Zhang, L.K. Shi. "Microstructure and formation mechanism of titanium matrix composites coating on Ti–6Al–4V by laser cladding", Rare Metals, Volume 26, Augest 2007, pp.342–6.

[13] M. Zheng, D. Fan, X.K. Li, W.F. Li, Q.B. Liu, J.B. Zhang, "Microstructure and osteoblast response of gradient bioceramic coating on titanium alloy fabricated by laser cladding", Applied Surface Science, Volume 255, November 2008, pp.426–428.

[14] Y. Huang, Y.J. Wang, C.Y. Ning, K.H. Nan, Y. Han, "Preparation and properties of a cerium-containing hydroxyapatite coating on commercially pure titanium by micro-arc oxidation", Rare Metals, Volume 27, June 2008, pp.257–60.

[15] H.J. Song, S.H. Park, S.H. Jeong, Y.J. Park, "Surface characteristics and bioactivity of oxide films formed by anodic spark oxidation on titanium in different electrolytes", Journal of Materials Processing Technology, Volume 209, January 2009, pp.864–870.