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Investigation on the effect of microstructure and mechanical properties of laser cladded TC17 titanium alloy following laser shock peening

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Abstract. This paper aims to determine the effects of microstructure and mechanical properties of laser cladding TC17 titanium alloy post laser shock peening (LSP). In this work, A 3J, 20ns, 1064nm wavelength, Nd:YAG laser was employed on laser cladded TC17 titanium alloy samples with multiple impacts. Micro-hardness, residual stress were measured. The microstructure of LSPned sample was mapped by Electron Backscattered Diffraction (EBSD). The residual stress results showed that a stable compressive residual stress has been formed on the cladded coating surface with a value of 190MPa due to LSP modification. Additionally, LSP also improves the surface microhardness of cladded TC17 samples with an increase rate of 13.1%. Vibration fatigue tests were designed and carried out to examine the effects of LSP on the fatigue strength of cladded TC17 specimens. Results show that the fatigue strength of unpeened cladded sample is 290MPa while of peened cladded sample is 300MPa. This work will contribute to prolong the service life of repaired TC17 components in aero-engines thereby economizing the repairing costs.

1. Introduction

TC17 (Ti-5Al-2Sn-2Zr-4Mo-4Cr) titanium alloy is a $\alpha + \beta$ phase alloy which possesses high mechanical strength, excellent fracture toughness, and high hardenability [1]. That is why TC17 alloy has been widely employed in aero-engine compressor blisks and fan blade. Repairing such components is not only economic cost issues but also time-consuming. At present, in the aero industry, damaged components are repaired by laser cladding which has advantages such as low cost, less distortion and being environment-friendly *etc* [2]. However, due to the thermal extremely changing during laser cladding processing, tensile residual stress may easily formed in the bonding zone. As reported in many literatures [3-5], tensile residuals stress may lead to the decrease the fatigue life of metal specimens. This will definitely increase the economic cost and effect the safety of end-user.

Therefore, in this paper, Laser shock peening, as innovative surface modification technique, is employed to improve the mechanical properties such as microhardness, residual stress and fatigue strength [3-4]. K.Y. Luo et al. [5] investigated the effects of multiple LSP on micro-hardness, residual stress and microstructure in different zones of laser cladding. It found that LSP brings an obvious improvement in microhardness and residual stress on the surface layer of cladding coatings.



Additionally, Zhang et al. [6] have completed some similar works on K403 nickel-alloy. LSP was applied to strengthen the surface repaired region of K403 nickel-alloy. Similarly, the found that after LSP the hardness of substrate and cladding zone were increased by 21% and 8%, respectively, and 610MPa compressive residual stress was formed on the K403 alloy surface. As discussed above, in terms of fatigue strength of metal laser cladding has not been studied yet. Therefore, in this paper, the effect of LSP on the fatigue strength of laser cladding is investigated. This work will directly contribute to prolong the services time of aero-engine components.

2. Materials and methods

2.1. Details of TC17 alloy and sample preparation

TC17 is a kind of transformed β titanium alloy, which consists of primary α phase and acicular $\alpha+\beta$ colonies (Transformed- β). The TC17 samples were cut into a small piece with a dimension of 100mm x 10mm x 1mm (shown in Figure 1), ground from 300 to 1200 grit size with SiC paper in the stage. In terms of EBSD mapping, the analysis was conducted with a field emission scanning electron microscope (Sigma 500Vp, Zeiss, Germany) equipped with a AZtec EBSD system. The TC17 alloy powder employed in this paper was bought from Baotai Company, Shanxi, China and its elemental composition is shown in Table 1.

Table 1. Element composition of TC17 alloy (wt%).

Composition	Al	Mo	Cr	Sn	Zr	O	C	Fe	N	H
Content(wt%)	4.7	3.9	3.9	1.9	1.9	0.1	0.01	0.06	0.009	0.004

2.2. Laser processing methods

The schematic diagram of LSP is shown in Figure 1. And the LSP experiments were conducted by a Q-switched Nd:YAG laser (Tyrida, Xi'an, China). The detailed processing parameters are listed in the following Table 2.

A 1KW Continuous CO_2 laser (Xian Bolite co., Ltd) was employed to clad titanium powder. Laser output power is 600w; Scanning speed is 7mm/s; Overlapping rate is 30%; High purity argon gas was used as the shielding gas protecting from oxidization during processing.

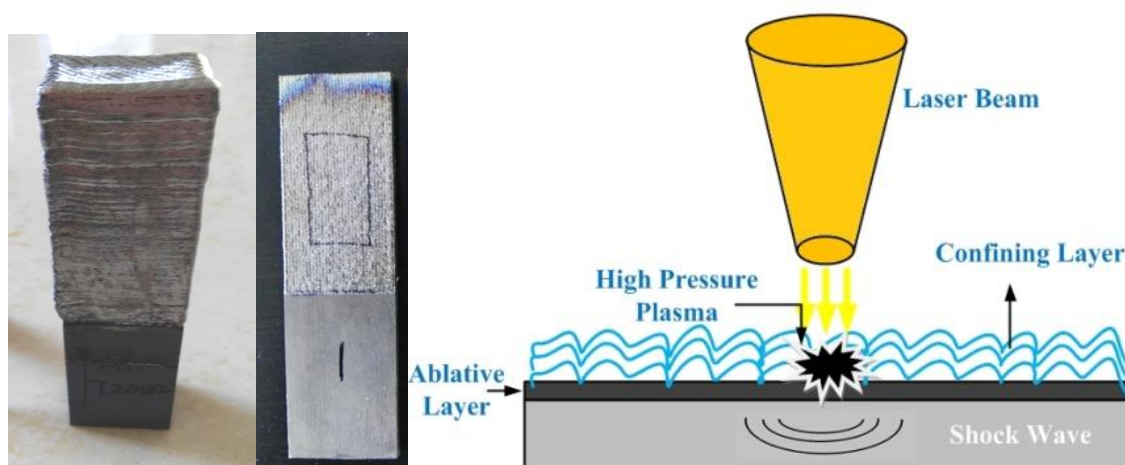


Figure1. Laser cladded TC17 sample and LSP schematic diagram.

Table 2. Laser shock peening parameters for TC17 titanium alloy.

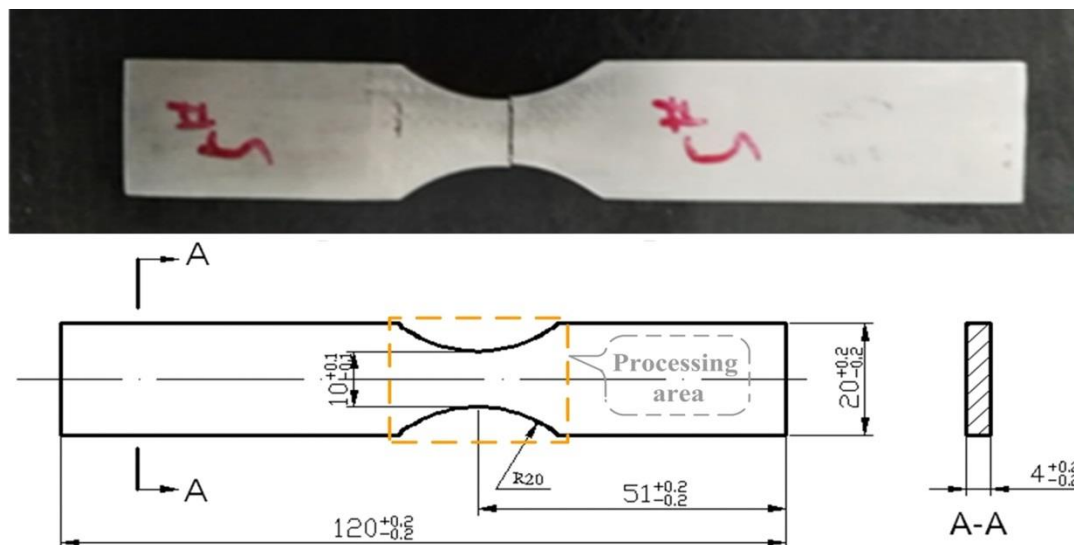
Parameters	Value
Wavelength(nm)	1064
Pulse energy(J)	3J
Spot size(mm)	2.5
Pulse duration(ns)	20
Impact number	2
Overlapping rate (%)	50

2.3. Characterization of experiments: Microhardness, Residual Stress, and Fatigue Strength

The Struer Hardness tester, with a load of 0.9g and a dwell time of 15s, was employed to measure the surface Vickers microhardness distributions. The measurement was carried out with a spacing of 2mm between two successive points along with the additive manufactured direction. And each point was the mean value of 5 measurements

Residual stress on both peened and unpeened samples were measured using X-ray diffraction method (Bruker D8 Discover; Germany). The X-ray source was operated at the voltage of 40kV and current of 35mA. Measuring residual stress on the titanium samples surfaces were performed using Cu-K α radiation (wavelength: 0.15418nm). The {213} lattice planes were selected for residual stress calculation.

The vibration fatigue experiments were carried out using self-designed vibration system, at room temperature. The size of fatigue specimens and the tested fatigue specimens are shown in Figure 2. The resonant frequency of TC17 alloy is around 273HZ. Thus, an up-and-down fatigue method was employed to determine the fatigue strength.

**Figure 2.** The cracked TC17 specimen and the dimension of fatigue specimens.

3. Results

3.1. Residual Stress

Due to the changing thermal and plastic deformation, tensile residual stress was normally formed during laser cladding. As an innovative surface modification technique, one of advantages of LSP is that a stable compressive can be formed by LSP on the top metal surface. Figure 3 shows that residual stress distributions of TC17 surface before and after LSP. In Figure 3, red curve stands for as-received laser cladded sample while the black curve is LSPned sample. The centre point 0 is the interface of

substrate and cladding area along the X direction. It can be seen that test points' value of as-received sample along the additive manufactured direction are all tensile residual stress, varying from 0MPa to 260MPa, from substrate to cladding area. Specifically, in terms of cladding area, the tensile stress increases from 180MPa (near the centre point) to the maximum value of 260MPa at the centre point. After that, the stress become stable at around 190MPa. By contrast, the curve of laser shock peened has a great improvement of compressive residual stress. In the substrate area (from -12mm to -4 mm), the residual stresses are decreased to about -80MPa, onwards along the cladding direction, decreasing dramatically to -200MPa near the centre point. In cladding area, the residual stresses keep its steady, forming a stable compressive residual stress layer with a value of 180MPa. The distributions compressive residual stress are comparatively uniform which could benefits to the fatigue life of TC17 components.

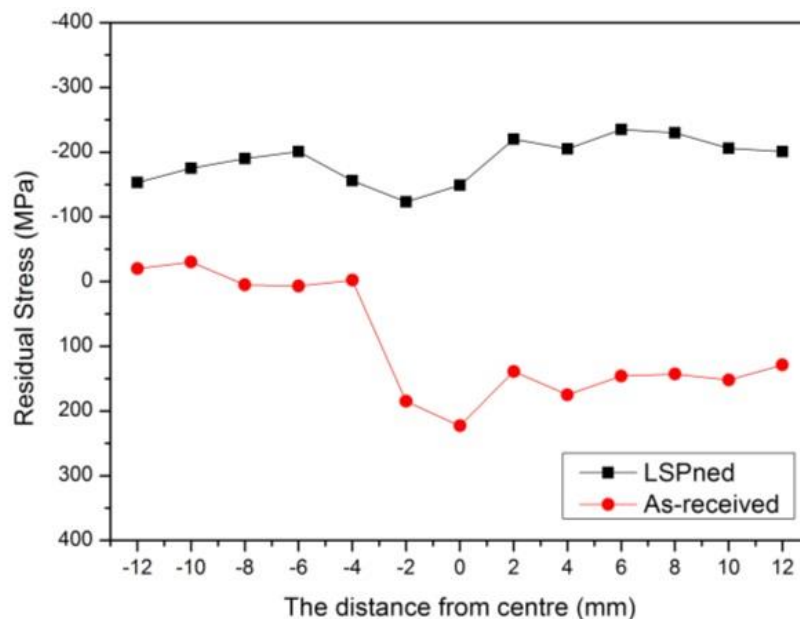


Figure 3. the surface residual stress distributions of TC17 titanium alloy before and after Laser shock peening.

3.2. Microhardness

Reported by the literatures [7-9], LSP has a significant influence on metal surface microhardness. Shown in Figure 4, it is the comparison of surface microhardness distributions along the repairing direction subject to laser shock peening. The measured areas are divided into three components, which are substrate, bonding zone and cladding zone. Overall, it can be seen that cladding zone is the hardest with a maximum value (the mean value of 5 testing points in substrate) of 429 HV_{0.9}, followed by bonding zone (405 HV_{0.9}) and substrate (339 HV_{0.9}). In terms of as-received sample, the microhardness line processes the same trend with of peened sample. Cladding zone reaches the highest hardness at 382HV_{0.9} while in substrate, the hardness is the lowest at 305HV_{0.9}. In bonding zone, it is 349HV_{0.9}. These data indicate that LSP increase the surface microhardness by around 12.1%.

3.3. EBSD analysis

Figure 5 shows the EBSD image of laser cladded sample subject to LSP. After been cladded, the microstructure is not very uniform. Most grain sizes are about 5-20 μm . Due to the cladding thermal effects, some grains sizes may increase to 100 μm . TC17 alloy consists by α phase and β phase. It can be seen that β grains were cladded into waves shapes as the scanning method and trails. Additionally, among the structure, there are massive α grains as the α phase is the primary phase. According to the polar and un-polar images, there are no obvious preferred grains orientations.

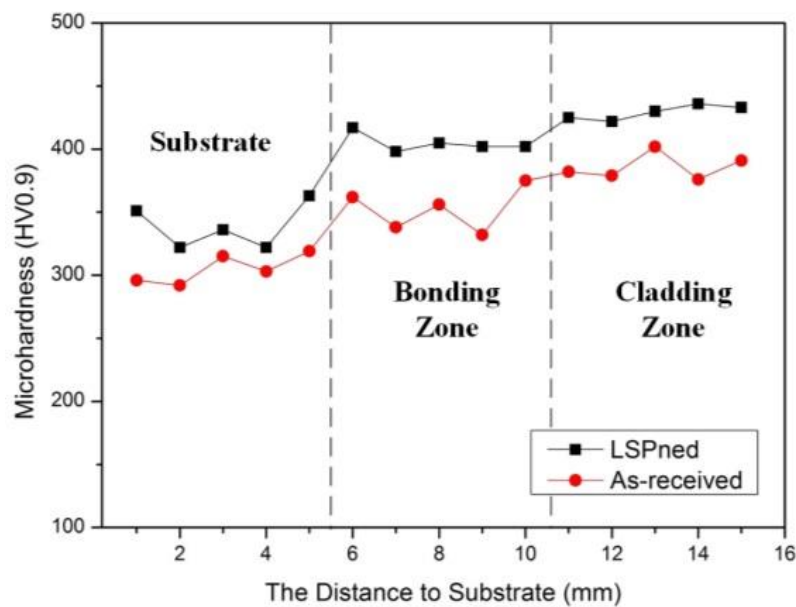


Figure 4. the distributions of surface microhardness of TC17 titanium alloy.

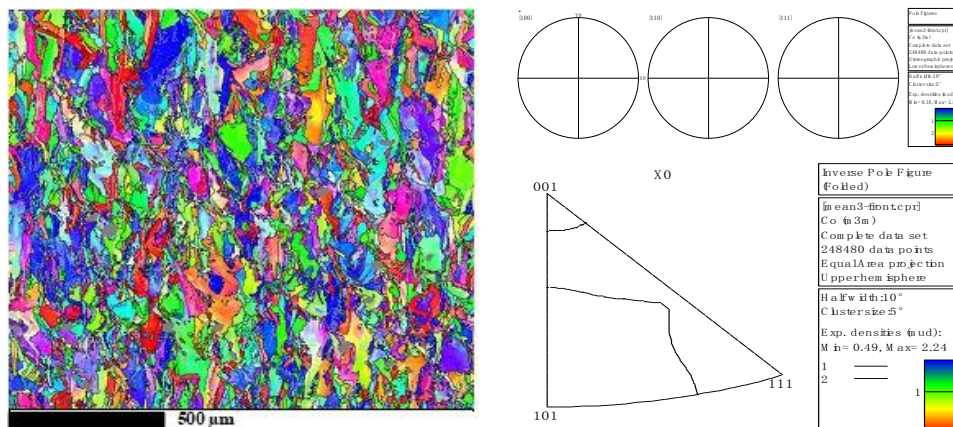


Figure 5. EBSD image of laser cladded TC17 titanium alloy following LSP.

3.4. Vibration Fatigue

Figure 6 shows the up-down curves of TC17 titanium with or without LSP. According to up-down statistics method, the fatigue strength of unpeened cladded specimens are 290MPa while the peened samples reach to 300MPa, with an increase of 3.4%. The increase of laser shock peening on fatigue strength is comparative small in this case due to the following two reasons: Firstly, Pulse energy is 3J which may not form enough shock wave for the surface microstructure refinement. Secondly, inside the cross-section of cladding zone, there are still some microstructure defects, which may affect the fatigue strength. This means laser cladding parameters have more influence on the fatigue strength.

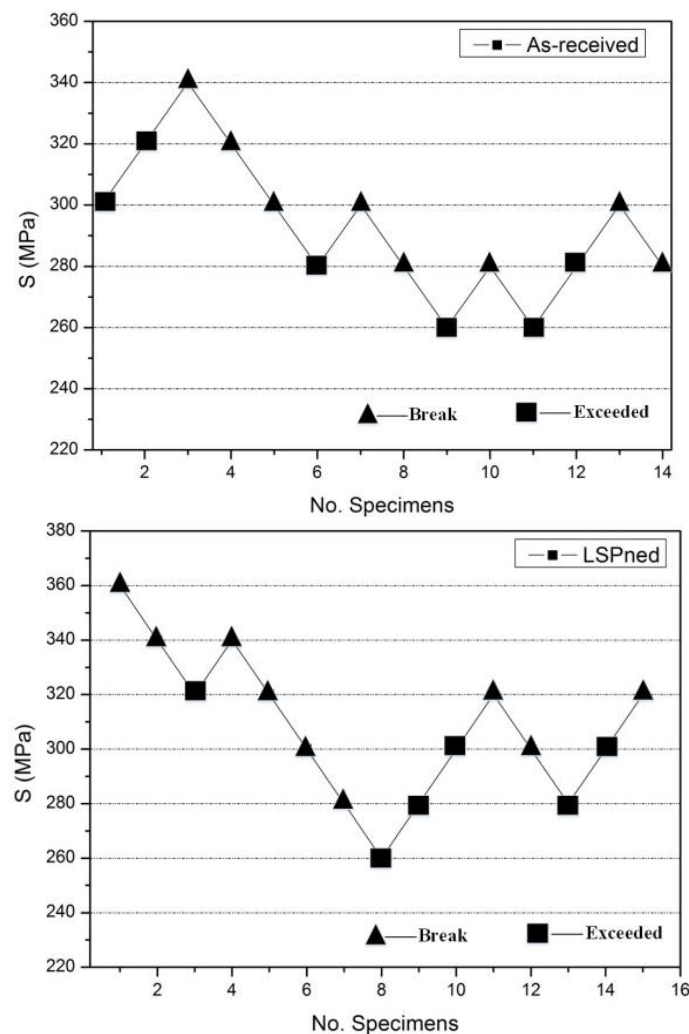


Figure 6. The up-down fatigue curves of TC17 titanium alloy.

4. Conclusion

The main acquired conclusions are listed as following:

(1) Residual Stress of cladded specimens was tested, and from the comparison between LSPned and as-received samples, LSP is an effective method to eliminate surface tensile residual stress, transforming into compressive residual stress on the material surface.

(2) The microhardness of LSPned sample is 13.1% higher than as-received sample over the different zone including substrate (11.1%), bonding zone (16%), and cladding zone (12.3%).

(3) The fatigue strength of cladded samples is 290MPa, while of cladded sample subject to LSP is 300MPa.

Reference

- [1] Q Liu, Y Wang, H Zheng, K Tang, H Li, S Gong 2015 Wire feeding based laser additive manufacturing TC17 titanium alloy *Materials Technology* **31** 108-114
- [2] Qi Liu, Y Wang, H Zheng, K Tang, Huaixue Li, Shuili Gong 2016 TC17 titanium alloy laser melting deposition repair process and properties *Optics&Laser Technology* **82** 1-9
- [3] Xiaojun Shen 2017 Pratik Shukla, Subhasisa Nath, Jonathan Lawrence Improvement in mechanical properties of titanium alloy(Ti-6Al-7Nb) subject to multiple laser shock peening *Surface&Coating Technology* **327** 101-109

- [4] C Wang, XJ Shen, ZB An, LC Zhou, YChai 2016 Effects of laser shock processing on microstructure and mechanical properties of K403 nickel-alloy *Materials&Design* **89** 582-588
- [5] KY Luo, XJing, J Sheng, GF Sun, Z Yan, JZ Lu 2016 Characterization and analyses on micro-hardness, residual stress and microstructure in laser cladding coating of 316L stainless steel subjected to massive LSP treatment *Journal of Alloys and Compounds* **673** 158-169
- [6] Zhang Peiyu, Wang Cheng, Xie Mengyun, Li Yuqin, Zn Zhibin Effect of laser shock processing on microstructure and properties of K403 alloy repaired by laser cladding *Infrared and Laser Engineering* **46(9)** 0906003-1-7
- [7] CWang, XJ Shen, ZB An, LC Zhou, Y Chai Effects of laser shock processing on microstructure and mechanical properties of K403 nickel-alloy *Material&Design* **89(5)** 582-588
- [8] An Zhibin, Shen Xiaojun, Gao Shan Wang Cheng 2016 Nanocrystallization of Ni-based superalloy K403 by laser shock peening *Infrared and Laser Engineerin* **45(9)** 0921002
- [9] Pratik Shukla, Subhasisa Nath, Guanjun Wang, Xiaojun Shen 2017 Jonathan Lawrence Surface properties modifications of silicon carbide ceramic following laser shock peening *Journal of the European Ceramic Society* **37** 3027-3038