

Residual Stress Analysis on Titanium Alloy TC4 by Laser Shock Peening

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Abstract—Laser shock peening (LSP) is a new technique to reinforce the surface of materials, and the fatigue strength, wear properties and residual stress corroding properties of metallic materials would be greatly improved by shock peening. The residual compressive stress distribution caused by LSP from the surface to 500μm below the surface of the titanium alloy TC4 were measured by X-ray stress analyzer. Results indicated that there was a large residual stress on the surface of the shocked material. When the power density was 3 GW/cm², the residual compressive stress on the surface reached 650 MPa, and it decreased gradually with the depth increased. It maintained 300 MPa when the depth was 500μm. Effect of the power density on the residual compressive stress distribution was also investigated. As the power density increased, the residual compressive stress on the surface also increased. The fatigue resistance of titanium alloy TC4 would be greatly improved.

Keywords—laser shock peening; residual stress; TC4 titanium alloy; X-ray diffraction

I. INTRODUCTION

Titanium and titanium alloy has a series of advantages such as high specific strength, good corrosion resistance, and high temperature resistance. They have more and more applications in the modern aircraft, engine and airborne equipment [1]. The consumption has become an important index to measure the plane is advanced or not. However, low fatigue strength, big dispersion, low hardness and poor wear resistance faults of titanium and titanium alloy cause them particularly sensitive to fretting fatigue, which limit their further application [2]. In recent years, the domestic and foreign scholars launched a wide range of research for all kinds surface treatment technology and achieved some results [3-5]. Laser shock peening (LSP) is a new technique to reinforce the surface of materials, and the fatigue strength, wear properties and residual stress corroding properties of metallic materials would be greatly improved by shock peening. Compared with the traditional surface strengthening technology, it has certain advantages. In this paper, the LSP treatment and residual stress of the strengthening layer are studied by X-ray method.

II. EXPERIMENT

The dimension of titanium alloy TC4 is 40mm×40mm×6mm (see Fig. 1), the chemical composition is the list in Table 1. According to the relevant theory and experience, determine the LSP parameters as follows: light spot

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diameter d equals to 3-4 mm, power density I equals to 2.30 to 7.00 GW/cm², laser pulse width τ equals to 20 ns, energy E₀ equals to 1.84-7.80J, efficiency coefficient α equals to 0.25, absorption rate A equals to 0.9. The absorption layer is aluminum foil.

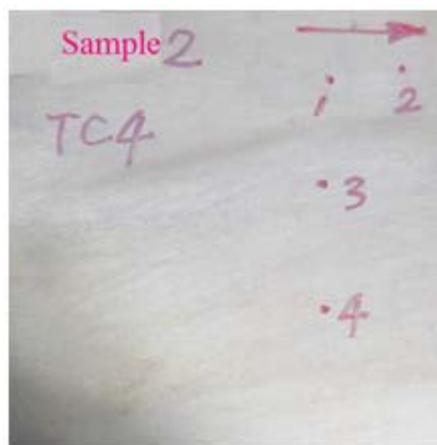


Fig. 1. TC4 sample with different points treated by LSP

TABLE I. CHEMICAL COMPOSITION OF TC4

Chemical composition	Al	V	Fe	Si	C	N	H	O
Wt%	5.5-6.8	3.5-4.5	≤0.30	≤0.15	≤0.15	≤0.05	≤0.015	≤0.20

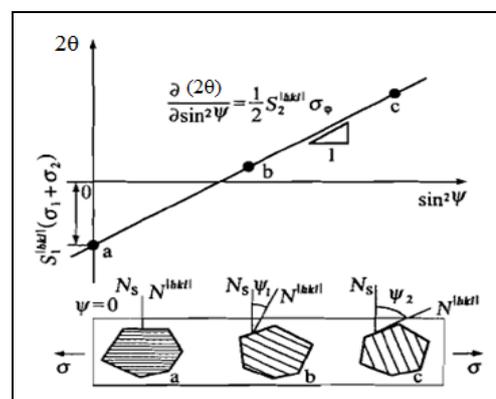


Fig. 2. The schematic of residual stress measurement by sin²ψ method

The X-ray measurements were made with a X-350A type stress analyzer. The classical $\sin^2\Psi$ method (see Fig. 2) was used to determine the stress.

Residual stress calculation:

$$\sigma = K \cdot M \quad (1)$$

Among them:

K is X-ray stress constant

$$M = \partial(2\theta) / \partial(\sin^2\Psi)$$

The stress analyzer operates at 27 kV and a 6mA current. The diameter of the spot was 3 mm. The choice of X-ray tube anode and, therefore, the wavelength of the incident beam is critical for the determination of residual stress. Residual stress calculated by using different wavelengths may have different values because of the different penetration depth of the X-ray beam into the sample. Using reflections with 2θ angles less than 120° is not recommended because of the low sensitivity of strain measurement.

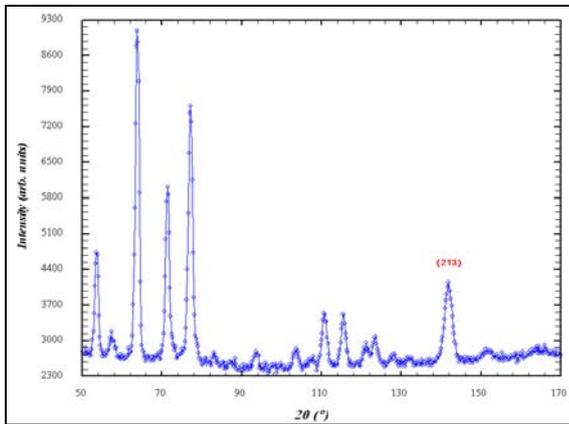


Fig. 3. Full pattern collected using X-ray with a copper target.

Any mechanical or electro discharge machining method to remove surface layers of the sample will induce residual stress, altering the stress field of the surface. But chemical attack or electro polishing is suggested to remove layers without introducing new stresses on the surface. So in this studies, it is using chemical etching method to sample thinning [2]. The corrosion solution include 24% (volume fraction, the same below) HNO_3 , 14% HF and 62% H_2O , corrosion rate is 0.2-0.5 $\mu\text{m/s}$.

III. RESULTS AND DISCUSSION

As can be seen from Fig. 4, the residual stresses after laser shock processing are compressive stress, the maximum value is on the surface, and gradually decreases with the increase of the depth in the sample, the changing rate of residual compressive stress is larger before 200 μm , when the depth reaches about

500 μm the residual compressive stress is still about 100 MPa. The residual compressive stress on the surface reached 650MPa at the power density was 3 GW/cm^2 , and it decreased gradually with the depth increased, it maintained 300MPa when the depth was 500 μm .

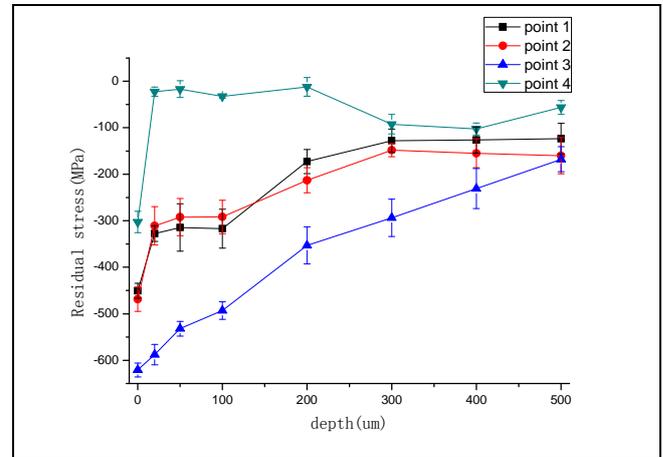


Fig. 4. The residual stresses vs corrosion depth of TC4.

Laser shock processing uses the mechanical effects of laser shock wave, and form very high compressive residual stress on the metal surface, almost no crack length increases with the increase of the cycles, thus greatly extend the fatigue life of metal. From the investigation of the effect of power density on the residual compressive stress distribution could conclude that along with the power density increased, the residual compressive stresses on the surface were also increased. So the fatigue resistance of titanium alloy TC4 would be greatly improved. Laser shock processing can make high residual compressive stress on the surface and deep inside of the material. The influence of compressive stress could balance the material tensile stress in use, convert part of the tensile stress to compressive stress, and delay the generation of fatigue crack and the expansion speed.

IV. CONCLUSIONS

After laser shock processing, the surface microstructure of TC4 alloy could be changed to improve the mechanical properties. When the power density was 3 GW/cm^2 , the residual compressive stress on the surface reached 650MPa, and it decreased gradually with the depth increased, it maintained 300MPa when the depth was 500 μm . As the power density increased, the residual compressive stress on the surface also increased. So the fatigue resistance of titanium alloy TC4 would be greatly improved by laser shock processing.

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