

## Effect of Laser Peening on Residual Stress and Micro-hardness of TC4 Titanium Alloy

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**Abstract:** Laser peening offers potential advantages over conventional peen technologies in terms of the depth of the residual stresses that can be induced, and improvements in surface micro-hardness. The present study was undertaken to understand the effect of laser peening on the properties of titanium alloy, a TC4 titanium alloy work-piece was processed with ND: YAG laser with the wavelength of 1064 nm, pulse energy of 0-10J and pulse width of 12ns, and micro-hardness and residual stress for different laser peening parameters were examined and analyzed by micro-hardness tester and X-ray diffraction. Results are presented and discussed of the residual stress profiles and the micro-hardness profiles, The experimental results show that the satisfying laser peening appearance can be achieved when the pulse energy was 6J, water tamping layer thickness was 1.8mm and ablative layer thickness was 100μm, surface micro-hardness increased by up to 33% and the compressive residual stress on the surface of laser shocked area reached up to -327.8MPa, laser peening improved hardness and residual stress of titanium alloy significantly. The experiment results show that the effect of laser peening was evidently.

### Introduction

Laser peening is a recently-developed surface treatment method designed to improve the performance and fatigue life of mechanical parts. The very first studies investigating the possibility of high energy laser beams to induce shock waves were done at the Battelle Columbus Laboratory in the 1970s[1-5]. Since then considerable attention has been paid to potential application of laser peening in the aerospace and nuclear industry. The beneficial effects of laser peening on static, cyclic, fretting fatigue and stress corrosion performance of aeronautical and automotive aluminum alloys, steels and nickel-based alloys have been demonstrated [6-10].

Fig.1 shows that laser peening treatment the work-piece is subjected to short duration pulses from a laser which generates confined plasma on the surface. The plasma has an extremely high pressure which is in turn transmitted into the work-piece via shock waves which plastically deform the near-surface region. The local plastic deformation induced beneficial compressive residual stress fields deep into materials [5-8].

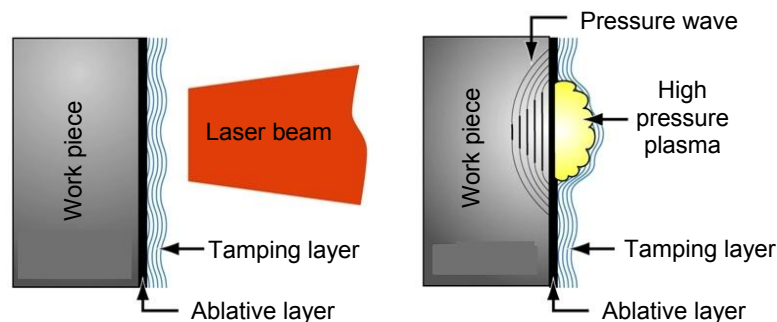


Fig.1. Schematic diagram of laser peening

There have been some investigation and theoretical predictions of residual stresses and fatigue performance of peened thin sheet material [11,12], but residual stresses in thin sheet different from those found in thick material, and in addition, there may be other effects associated with stress and micro-hardness. In order to investigate the benefits of laser peening in 10mm TC4 slab, this paper reports on an investigation into residual stresses and micro-hardness with different laser peening parameters.

## Materials and Experimental Techniques

Fig.2 shows the schematic of SIA-LSP-2 laser peening equipment. This equipment was designed and developed by Shenyang Institute of Automation Chinese Academy of Sciences. The ND: YAG laser with the wavelength of 1064 nm, pulse energy of 0-10J, frequency of 2Hz, and pulse width of 12ns, TC4 titanium alloy work-piece on the XY two-dimensional motion platform was driven by servo-motor's imputation movement. The laser beam of  $\Phi 22\text{mm}$  from the ND: YAG laser was transported by reflecting mirror and focusing lens, and the laser spot was formed on the surface of the work-piece with the diameter of  $\Phi 3\text{mm}$ .

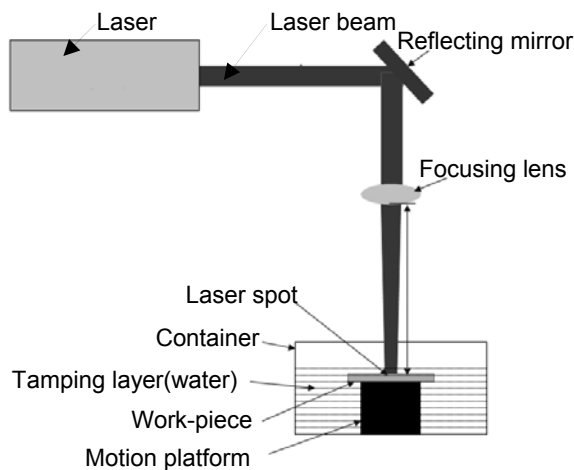


Fig. 2 Schematic of laser peening equipment



Fig. 3 Photo of work-piece after laser peening

TC4 titanium alloy work-piece was provided by the AVIC Shenyang Liming Aero-engine(Group) Corporation Ltd.. The TC4 titanium alloy was widely used in the aviation, and its chemical composition was shown in table 1.

Table 1 Chemical composition of TC4 (mass percentage, %)

Al	V	Fe	O	C	N	H	Ti
5.5-6.8	3.5-4.5	0.30	0.20	0.10	0.05	0.015	Bal.

The titanium alloy work-piece was cutted into the size of 100mm×50mm×10mm, and polished to surface roughness value of Ra0.6. Then, the work-piece was processed by vibration aging to eliminate the residual stress on the work-piece's surface. Before vibration aging, the residual stress on the work-piece changes between +15MPa and -15MPa, and distributed unevenly. After vibration aging, the residual stress on the work-piece changes between +1.5MPa and -1.5MPa, approaching to 0Mpa, and distributed evenly. Uniform surface residual stress of the work-piece can guarantee the reliability of the experiment data of the subsequent laser peening. Finally, the work-piece was cleaned with ethanol and deionized water to remove greasy dirt on the surface of work-piece, and dried by blowing purity nitrogen.

Firstly, the work-piece's surface was covered by a black tape ablative layer, and then rolled compaction by rubber roller to ensure that no bubbles between work-piece and black tape ablative layer. Deionized water was used as tamping layer, and was applied by water conveyance system to adjust the tamping layer thickness. Water conveyance system was composed of water tank, constant pressure pumps, flow sensor, leve gauge, flow valve and solenoid valve, and was controlled by host computer to ensure that the thickness of tamping layer continuously adjustable.

After laser peening, removed black tape tamping layer, and then washed the work-piece with ethanol to clean the residual gum. Micro-hardness for different laser peening parameters was examined by FM-300 micro-hardness tester, with loading force of 10gf and load time of 10s. Residual stress for different laser peening parameters was examined by X-ray diffraction. Fig.3 shows the photo of work-piece after laser peening.

## Results and Discussion

**Effect on pulse energy.** Using pulse width of 12ns, water tamping layer thickness of 1.8mm, spot overlapping rate of 40%, and changing the pulse energy. From the Fig.4, We can see that micro-hardness of the base metal was 407HV, and micro-hardness increased with the increase of pulse energy. Micro-hardness increased very slowly with the increase of pulse energy when pulse energy is less than 3J, indicating that there almost no effect on micro-hardness of work-piece when pulse energy is too low. Micro-hardness increased rapidly with the increase of pulse energy when pulse energy is more than 3J. Micro-hardness increased to 535HV with the pulse energy increasing to 6J.

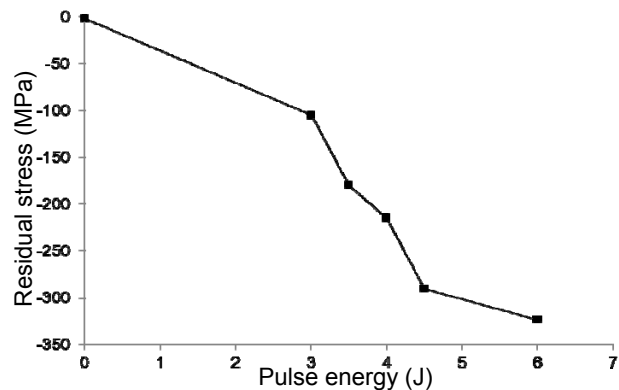
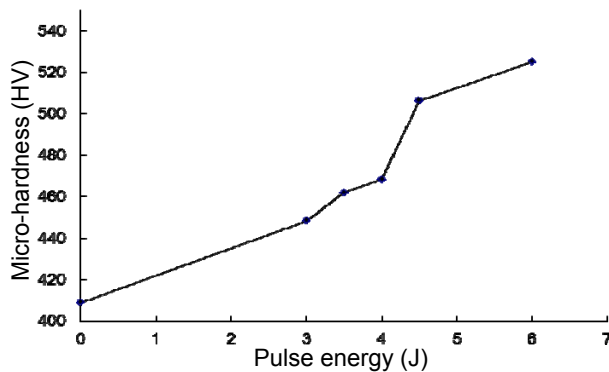


Fig.4 Effect of micro-hardness on pulse energy

Fig.5 Effect of residual stress on pulse energy

From fig.5, we can see that compressive residual stress increased very slowly with the increase of pulse energy when pulse energy is less than 3J, increased rapidly with the increase of pulse energy from 3J to 4.5J, and increased less rapidly with the increase of pulse energy from 4.5J to 6J.

The analysis shows that, with the pulse energy increasing, micro-hardness and compressive residual stress increased. When the pulse energy reached 6J, micro-hardness and compressive residual stress reached 535HV and 327MPa respectively, indicating that the treatment effect was more and more obvious with the increase of pulse energy.

**Effect on thickness of tamping layer.** Using pulse width of 12ns, pulse energy of 6J, spot overlapping rate of 40%, and changing the thickness of water tamping layer from 1mm to 3mm. From the Fig.6, We can see that micro-hardness first increased and then decreased with the thickness of water tamping layer increase. Micro-hardness increased very rapidly with the thickness of water tamping layer increase when the thickness of tamping layer is less than 1.8mm, and decreased with the thickness of water tamping layer increase when the thickness of tamping layer is more than 1.8mm, indicating that micro-hardness increased to 540HV with the thickness of tamping layer was 1.8mm. From fig.7, we can see that compressive residual stress first increased very rapidly and then decreased very slowly with the thickness of water tamping layer increase, indicating that compressive residual stress increased to 320MPa with the thickness of tamping layer was 1.8mm.

The analysis shows that, micro-hardness and compressive residual stress first increased and then decreased with the thickness of water tamping layer increase. Indicating that the binding force of water tamping layer increased with the thickness of the tamping layer increase, but it also absorbed more and more energy of laser pulse, so the energy which reached the ablative layer was reduced, thereby the strengthening effect was reduced.

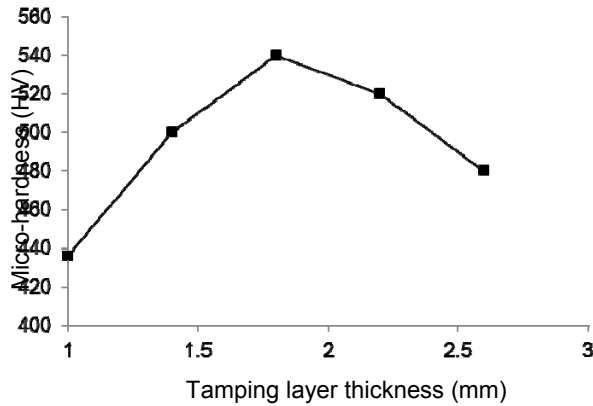


Fig.6 Effect of micro-hardness on tamping layer

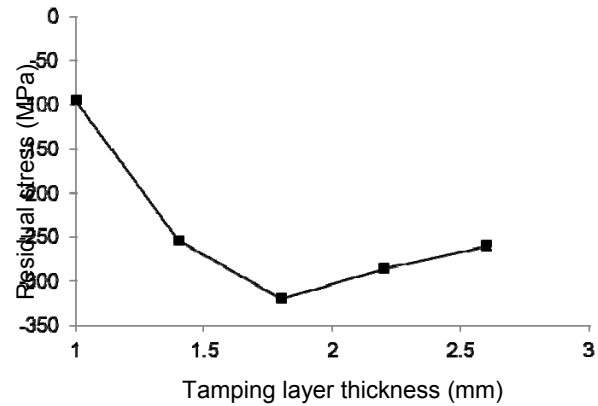


Fig.7 Effect of residual stress on tamping layer

**Effect on thickness of ablative layer.** Using water tamping layer thickness of 1.8mm, pulse energy of 6J, spot overlapping rate of 40%, and changing the thickness of ablative layer from 100 $\mu$ m to 180 $\mu$ m. From the Fig.8, We can see that micro-hardness decreased with the thickness of ablative layer increase. From fig.9, we can see that compressive residual stress decreased with the thickness of ablative layer increase.

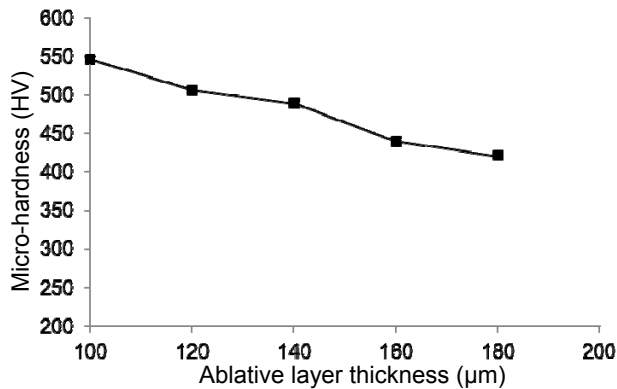


Fig.8 Effect of micro-hardness on ablative layer

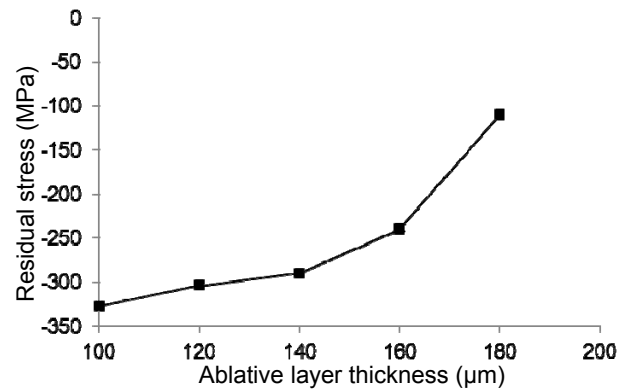


Fig.9 Effect of residual stress on ablative layer

The analysis shows that, micro-hardness and compressive residual stress decreased with the thickness of black tape ablative layer increase. Indicating that the black tape ablative layer absorbed more and more energy of laser pressure wave with the thickness of black tape ablative layer increase, so energy of pressure wave which reached the work-piece was reduced, thereby the strengthening effect was reduced. When the thickness of the ablative layer was less than 100 $\mu$ m, the ablative layer would be damaged by pressure wave, thereby the surface of work-piece would be damaged.

**Analysis of the effect on laser peening.** According to the experimental data shown in fig.2-fig.9 and analysis, the optimal laser peening parameters were selected. They are pulse energy of 6J, pulse width of 12ns, water tamping thickness of 1.8mm, and black tape ablative layer thickness of 100 $\mu$ m. Table 2 shows the experimental data before and after laser peening.

Table 2 Experimental data of before and after laser peening

No.	Micro-hardness before processing [HV]	Micro-hardness after processed [HV]	Residual stress before processing [Mpa]	Residual stress after processed [Mpa]
1	411	547	-1.4	-331
2	413	549	1.5	-318
3	405	543	1.2	-323
4	408	542	-0.5	-327
5	417	553	1	-340
Average	410.8	546.8	0.36	-327.8

From the table 2, We can see that micro-hardness value and residual stress value were 410.8HV and 0.36MPa before laser peening treatment, 546.8HV and -327.8MPa after laser peening treatment respectively. Micro-hardness increased by up to 33%, and compressive residual stress increased to

-327.8MPa after laser peening treatment, indicating that the laser peening treatment effect was very obviously.

## Conclusions

(1) For TC4 titanium alloy, by adjusting the pulse energy, the thickness of water tamping layer, and the thickness of black tape ablative, good treatment effect can be achieved.

(2) After laser peening treatment, micro-hardness increased by up to 33%, and compressive residual stress increased to -327.8MPa.

(3) Micro-hardness and compressive residual stress increased with the increase of pulse energy. Micro-hardness and compressive residual stress first increased and then decreased with the thickness of water tamping layer increase. Micro-hardness and compressive residual stress decreased with the thickness of black tape ablative layer increase.

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