Lasers in Manufacturing Conference 2021

Effect of femtosecond laser shock peening on surface morphology and hardness of nickel titanium alloy

Hao Wang[a,*], Evgeny L. Gurevich[b], Andreas Ostendorf[a]

[a]*Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany*
[b]*Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany*

Abstract

Nickel-titanium alloy (NiTi) has been widely used for the fabrication of microelectromechanical and body implants, so it is very important to enhance its surface mechanical property. Laser shock peening as a new and important surface treatment technique has been used to enhance the mechanical properties of different metal materials. Normally, the nanosecond laser with pulse-width between 5 ns and 20 ns is used to induce a high-pressure shock wave that can generate plastic deformation in the top layer of metals. In this paper, the surface morphology and hardness of NiTi alloy after femtosecond laser shock peening in the air are studied, which shows that the surface roughness and hardness increased after femtosecond laser treatment.

Keywords: nickel titanium alloy; laser shock peening; femtosecond laser; surface morphology; hardness

1. Introduction

Laser modification has been widely used to process the surface of metal materials, such as magnesium alloy, aluminum alloy, stainless steel and titanium alloy, which can improve their surface mechanical property and bioactivity [1][2]. Laser shock peening is an important surface technology, which is different from other laser process. The shock wave with high pressure would be produced by plasma explosion and nanosecond laser with pulse width of 5-20 ns can be used during laser shock peening [3][4]. The pressure of shock wave can be up to 10 GPa when nanosecond laser is used, which is much higher than the plastic deformation yield strength of metal materials. Therefore, the laser shock peening can induce plastic deformation and generate

* Corresponding author. Tel. 0234 / 32 23593; Fax. 0234 / 32 14259 555-1234.
E-mail address: wang@lat.rub.de.

compressive residual stress in the top layer of samples that would improve its mechanical property, such as microhardness, wear resistance, and fatigue life. The femtosecond laser shock peening has been studied to enhance the surface microhardness of different metals [5][6]. The researches found that the femtosecond laser can produce higher pressure of shock wave in a short time, which can be used modify the surface property of different materials. Li et al. found that femtosecond laser shock peening can increase the hardness by 45.5% on the surface of 304 stainless steel when the sample was processed without a protective layer and confinement coating [7]. Maharjan et al. also found similar results when they processed 420 martensitic stainless steel with femtosecond laser shock peening [8]. The NiTi alloy was treated by femtosecond laser shock peening and the surface property was measured in this paper.

2. Experimental process

The NiTi alloy specimen in this research was heated in 800 ℃ for 30 min before laser process. The femtosecond laser shock peening was performed with Spitfire Ace from Spectra-Physics with pulse energy of about 80 μJ. The NiTi alloy was polished like a mirror surface before the femtosecond laser shock peening treatment. During the femtosecond laser shock peening, there were no confinement layer and protective layer on the surface of NiTi alloy as shown in Fig. 1. After the laser process, the surface profiles were measured with laser scanning microscope of LEXT OLS 5000 and the surface hardness was measured by KB 30 BVZ hardness tester with load forces of 0.1 kg and 1 kg.

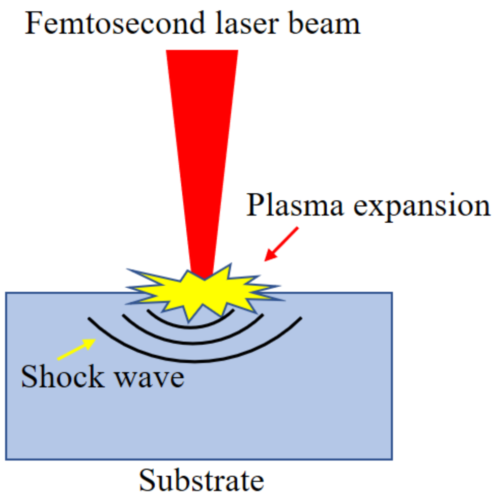

Fig. 1. Schematic of femtosecond laser shock peening without confinement layer and protective layer

3. Results

The 3D images of NiTi samples after femtosecond laser shock peening with different laser parameters were measured with a laser scanning microscope as shown in Fig. 2, in which the sample was processed in a half area. The results of 3D images showed that the femtosecond laser shock peening could induce higher roughness on the surface NiTi alloy compared with untreated sample. The 2D profiles along the surface of samples were presented in Fig. 3. It can be found that the texturing was formed which was due to the laser ablation and micro-deformation by high-pressure shock wave. The roughness of untreated sample was about

0.06±0.01 μm. The roughness values of samples with pulse densities of 7.14 ×10^5 pulse·cm^{-2}, 10 ×10^5 pulse·cm^{-2}, and 16.67 ×10^5 pulse·cm^{-2} were 0.35±0.01 μm, 0.38±0.02 μm, and 0.55±0.02 μm respectively. Normally, the higher roughness has an important on the effect of surface wear property and corrosion resistance of metal materials.

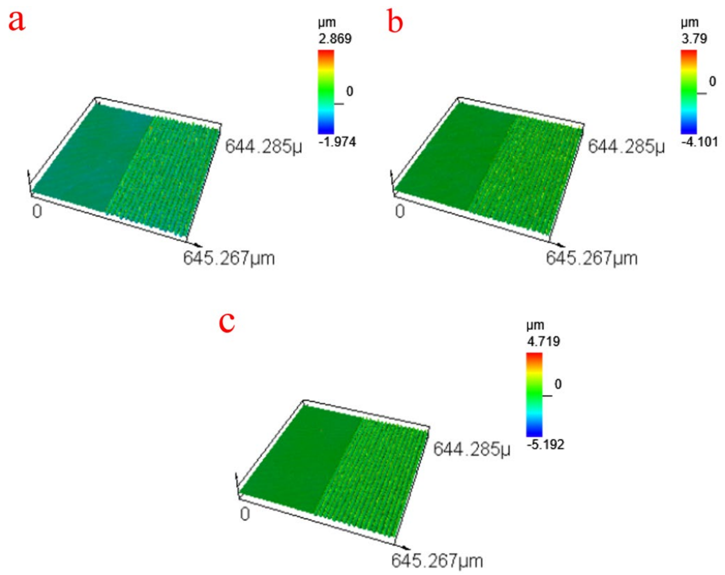

Fig. 2. 3D images of NiTi samples after femtosecond laser shock peening with different pulse density: (a) 7.14 ×10^5 pulse·cm^{-2}, (b) 10×10^5 pulse·cm^{-2}, and (c) 16.67 ×10^5 pulse·cm^{-2} (blue line).

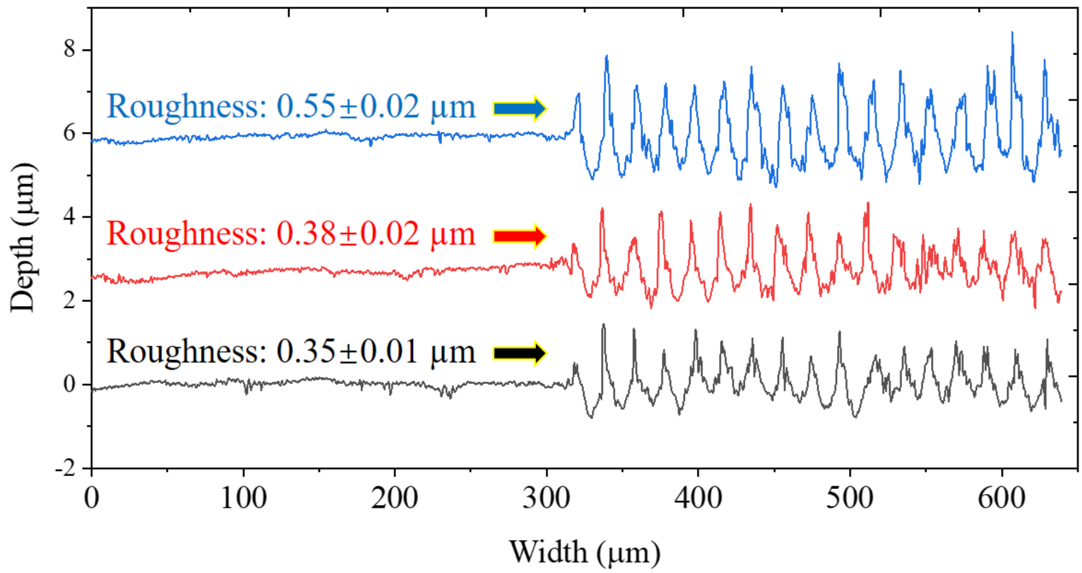

Fig. 3. 2D profiles of NiTi samples after femtosecond laser shock peening with different pulse density: 7.14 ×10^5 pulse·cm^{-2} (black line), 10×10^5 pulse·cm^{-2} (red line), and 16.67 ×10^5 pulse·cm^{-2} (blue line).

Laser shock peening is an effective method to increase the surface hardness and extend the fatigue life of metal parts, such as aluminum alloy, magnesium alloy, and stainless steel. The surface hardness of NiTi alloy was also measured with different load forces (0.1 kg and 1 kg). The mark pictures of load head during hardness testing were shown in Fig. 4 and Fig. 5. When the load force was 0.1 kg, the size of mark picture was samller than that measured with load force of 1 kg on the same specimen. From Fig. 4, it can be easily found that the size of mark picture on the surface of untreated NiTi alloy was larger than that of NiTi alloy after femtosecond laser shock peening. When the hardness was measured with load force of 0.1 kg, the hardness of untreated sample was 210.38±4.68 HV. The values of surface hardness on treated sample with pulse density of 7.14 $\times 10^5$ pulse·cm^{-2}, 10$\times 10^5$ pulse·cm^{-2}, and 16.67 $\times 10^5$ pulse·cm^{-2} were 256.76±20.84 HV, 264.28±18.39 HV, and 271.30±37.12 HV respectively. When the load force was 1 kg, the values of surface hardness after femtosecond laser shock peening with pulse density of 7.14 $\times 10^5$ pulse·cm^{-2}, 10$\times 10^5$ pulse·cm^{-2}, and 16.67 $\times 10^5$ pulse·cm^{-2} were 208.43±7.10 HV, 223.97±11.11 HV, and 237.19±6.71 HV, which were higher than 199.64±4.97 HV on the untreated sample. The hardness results demonstrated that the femtosecond laser shock peening can increase the surface hardness of NiTi alloy and larger pulse density would induce higher hardness. According to other research works, it can be found that the laser shock peening with ultrashort pulse laser was an effective method to enhance the mechanical property of different metals, such as aluminum alloy, magnesium alloy [9], stainless steel [10], and titanium alloy [11].

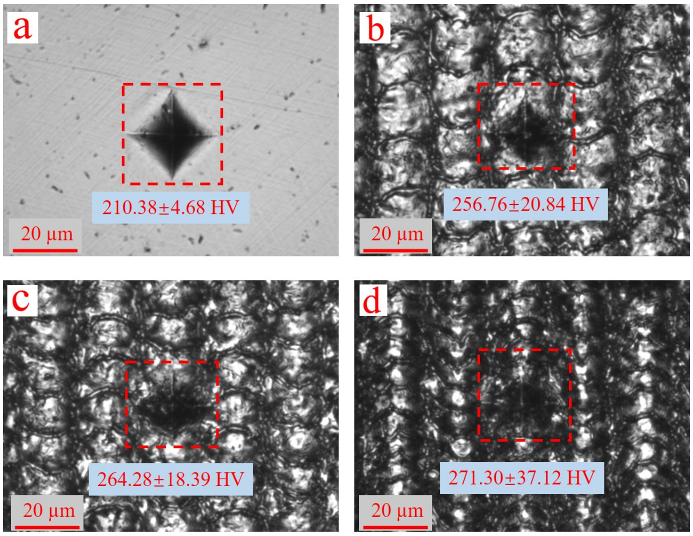

Fig. 4. Surface hardness (with load force of 0.1 kg) and topography on NiTi alloy with different treatment: (a) untreated, (b) femtosecond laser shock peening with 7.14 $\times 10^5$ pulse·cm^{-2}, (c) femtosecond laser shock peening with 10 $\times 10^5$ pulse·cm^{-2}, (d) femtosecond laser shock peening with 16.67 $\times 10^5$ pulse·cm^{-2}.

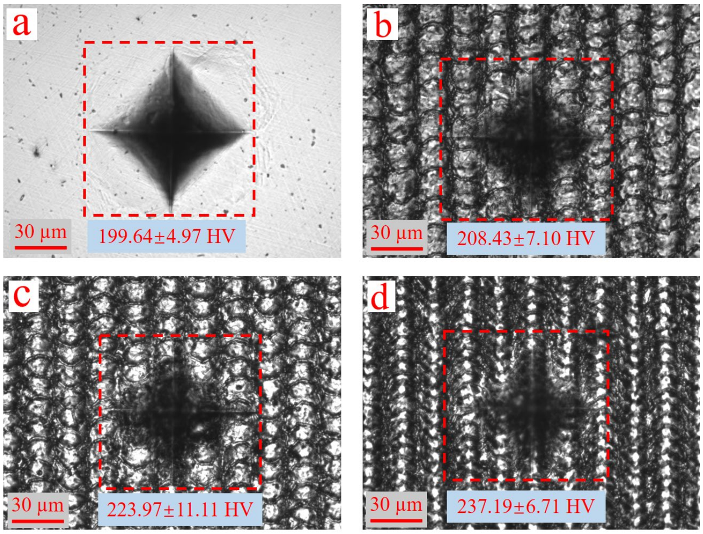

Fig. 5. Surface hardness (with load force of 1 kg) and topography on NiTi alloy with different treatment: (a) untreated, (b) femtosecond laser shock peening with 7.14 ×10^5 pulse·cm^{-2}, (c) femtosecond laser shock peening with 10×10^5 pulse·cm^{-2}, (d) femtosecond laser shock peening with 16.67 ×10^5 pulse·cm^{-2}.

4. Conclusions

The results showed that femtosecond laser shock peening could induce micro texture on the surface of NiTi alloy, which was due to the remelting layer by laser ablation and micro-deformation by high-pressure shock wave. The surface hardness of NiTi alloy with and without femtosecond laser shock peening treatment was measured with Vickers hardness method, which showed that the hardness increased with different pulse density.

Acknowledgements

This work is supported by the China Scholarship Council (CSC, No. 201706340042).

References

1. Yang, K.; Li, J.; Wang, Q.; Li, Z.; Jiang, Y.; Bao, Y. Effect of laser remelting on microstructure and wear resistance of plasma sprayed Al2O3-40% TiO2 coating. *Wear* **2019**, *426*, 314–318.
2. Malek, C.G.K. Laser processing for bio-microfluidics applications (part II). *Anal. Bioanal. Chem.* **2006**, *385*, 1362–1369.
3. Clauer, A.H. Laser shock peening for fatigue resistance. *Surf. Perform. Titan.* **1996**, *217*, 230.
4. Hfaiedh, N.; Peyre, P.; Song, H.; Popa, I.; Ji, V.; Vignal, V. Finite element analysis of laser shock peening of 2050-T8 aluminum alloy. *Int. J. Fatigue* **2015**, *70*, 480–489.
5. Hoppius, J.S.; Kukreja, L.M.; Knyazeva, M.; Pöhl, F.; Walther, F.; Ostendorf, A.; Gurevich, E.L. On femtosecond laser shock peening of stainless steel AISI 316. *Appl. Surf. Sci.* **2018**, *435*, 1120–1124.
6. Sano, T.; Eimura, T.; Kashiwabara, R.; Matsuda, T.; Isshiki, Y.; Hirose, A.; Tsutsumi, S.; Arakawa, K.; Hashimoto, T.; Masaki, K. Femtosecond laser peening of 2024 aluminum alloy without a sacrificial overlay under atmospheric conditions. *J. Laser Appl.*

2017, *29*, 12005.

7. Li, Y.; Ren, Z.; Jia, X.; Yang, W.; Nassreddin, N.; Dong, Y.; Ye, C.; Fortunato, A.; Zhao, X. The effects of the confining medium and protective layer during femtosecond laser shock peening. *Manuf. Lett.* **2021**, *27*, 26–30.
8. Maharjan, N.; Lin, Z.; Ardi, D.T.; Ji, L.; Hong, M. Laser peening of 420 martensitic stainless steel using ultrashort laser pulses. *Procedia CIRP* **2020**, *87*, 279–284.
9. Lu, C.; Ge, L.; Zhu, B.; Li, Y.; Chen, X.; Zeng, X.; Chen, Y. Effective femtosecond laser shock peening on a Mg–3Gd alloy at low pulse energy 430 µJ of 1 kHz. *J. Magnes. Alloy.* **2019**, *7*, 529–535.
10. Elango, K.; Hoppius, J.S.; Kukreja, L.M.; Ostendorf, A.; Gurevich, E.L. Studies on ultra-short pulsed laser shock peening of stainless-steel in different confinement media. *Surf. Coatings Technol.* **2020**, 125988.
11. Xinlei, P.A.N.; Weifeng, H.E.; Zhenbing, C.A.I.; Xuede, W.; Ping, L.I.U.; Sihai, L.U.O.; Liucheng, Z. Investigations on femtosecond laser-induced surface modification and periodic micropatterning with anti-friction properties on Ti6Al4V titanium alloy. *Chinese J. Aeronaut.* **2021**.