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Laser shock peening on high-strength steels

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ABSTRACT

High strength steel has been used in the aviation industry and automotive body structural applications to reduce its mass through a reduction in thickness. Therefore, it is very important to enhance its mechanical property, such as microhardness. In the present research, the high strength steel samples were treated by laser shock peening (LSP) with different laser pulse energy and laser pulse width. The microhardness and residual stress were measured to compare the difference between laser energy of 3 J with 10 ns and 5 J with 20 ns. The results in the study show that the surface LSP treatment can increase the microhardness and the compressive residual stress can be found when the samples were tested by hole drilling testing.

Keywords: High strength steel, microhardness, residual stress, laser shock peening

1. INTRODUCTION

High strength steel with a yield strength of more than 460 MPa has been widely used in different engineering machinery and structures like roadway and bridges, which can decrease the weight of the whole structure because of its high strength[1][2]. It is very important to improve the mechanical property of high strength steel during the industry application[3]. At present, lots of researches have been done to study the effect of surface treatment on the mechanical property of steel such as surface microhardness, wear resistance, and fatigue life[4][5][6]. A surface modification method called shot peening technology has been sued widely to enhance surface microhardness and generate compressive residual stress, which can improve its fatigue durability and corrosion property[7][8]. In the present research, laser shock peening technology was used instead of traditional shot peening. Because the LSP modification can induce a larger thickness layer with higher compressive residual stress than that by shot peening[9]. The thickness of the affected layer with compressive residual stress can be up to 1000 µm. During LSP treatment, Q-switched Nd: YAG laser with a pulse energy of 200 mJ – 20 J and pulse width of 5 ns – 20 ns is used normally. Many researches have found that laser shock peening modification can enhance the mechanical property and fatigue property of different metals[10]. In our study, we used laser shock peening to treat aviation aluminum alloy (2024Al and 7075Al) and ship aluminum alloy (5083Al) and found that the LSP treatment would generate compressive residual stress and increase microhardness of the alloys[11][12][13]. Tong et al. also found a similar result when they processed the 5083Al to improve its cavitation erosion resistance[14]. Yang et al. used LSP modification to improve the mechanical property and fatigue life of 2024Al with a fastener hole and their results show that the surface LSP treatment is a very good way to increase the fatigue time of 2024Al[15]. Sikhamov et al. study also LSP treatment on AA2024Al with a Fastener Hole and found that the treatment is a positive technology on the mechanical property of AA2024Al in their study[16]. Correa et al. processed 316L stainless steel with laser shock peening and they found that the fatigue life of 316L steel increased up to 471% when process parameters were changed[17]. Nanosecond laser shock peening, picosecond laser shock peening, and femtosecond laser shock peening have been used to enhance the surface microhardness of different materials[18][19][20][21][22]. In the present study, the high strength steel was treated by LSP modification by a nanosecond laser system with different pulse energy and pulse width, and the surface microhardness and residual stress were measured.

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2. EXPERIMENTAL DETAILS

When the ultrashort laser beam passes through a transparent overlay (water film of 1-2 mm thick) and irradiates on protective coating (steel tape of 100 μm thick) on the surface of metals, which can immediately induce plasma exposition between the transparent and protective overlays to generate a high-pressure during LSP treatment (as shown in Fig. 1). The LSP modification would produce grain refinement and generate compressive residual stress in the metal samples. During the laser processing, the high strength steel was treated by nanosecond laser with higher energy. Pulse energies of the single laser shot were 3 J with 10 ns and 5 J with 20 ns and the wavelength of the laser was 1064 nm with a repetition of 10 Hz. The shape of the laser spot is square with a size of 1 mm * 1 mm. The distance between the center of the laser spot was 1 mm, which means that the overlapping is 0% during the process which can be found in Fig. 2. The parameters of the LSP treatment can be found in Tab. 1. All the samples were cleaned in alcohol for 30 min before and after the surface LSP process.

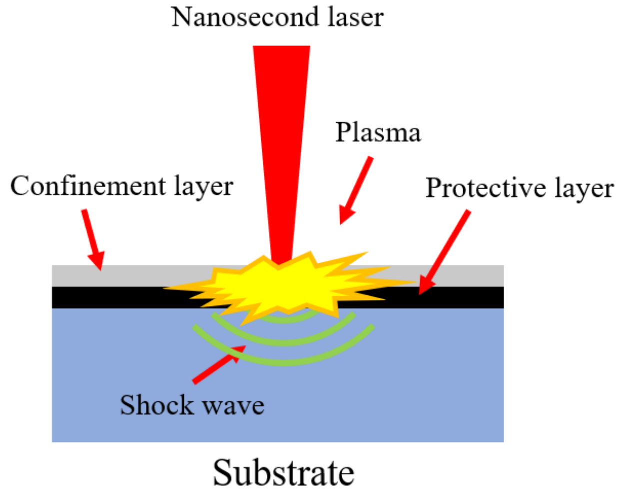

Figure 1. Schematic principle of laser shock peening in the present study.

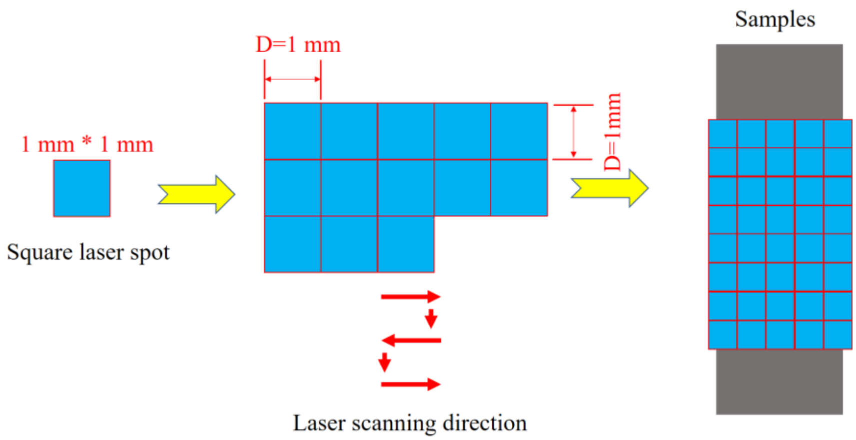

Figure 2. The schematic view of the laser shock peening process.

Table 1. Information on the laser shock peening on steel with different parameters.

	Sample 1	Sample 2
Laser energy	3 J	5 J
Pulse width	10 ns	20 ns
Repetition	10 Hz	10 Hz
Overlapping	0	0
Size of the square laser spot	1 mm × 1 mm	1 mm × 1 mm

After the LSP process, microhardness on the surface of high strength steel, and along the cross-section of high strength steel was measured with a different load force of 0.1, 0.3, 0.5, 1, 2, and 5 Kg respectively. A hole drilling device was used to test the residual stress at different depths with and without the LSP process.

3. RESULTS AND DISCUSSION

Fig. 3 gives the microhardness of high strength steel before and after the LSP process. The results were measured with a different load force of 0.1, 0.3, 0.5, 1, 2, and 5 Kg, respectively. The values of surface microhardness of untreated sample with 0.1 Kg, 0.3 Kg, 0.5 Kg, 1 Kg, 2 Kg, and 5 Kg were 262±6 HV, 253±4 HV, 245±3 HV, 240±3 HV, 238±4 HV, and 248±1 HV respectively. The values of surface microhardness of LSPed sample by 3 J and 10 ns with 0.1 Kg, 0.3 Kg, 0.5 Kg, 1 Kg, 2 Kg, and 5 Kg were 283±9 HV, 273±3 HV, 266±5 HV, 271±3 HV, 271±3 HV, and 269±3 HV, respectively. The values of surface microhardness of LSPed sample by 5 J and 20 ns with 0.1 Kg, 0.3 Kg, 0.5 Kg, 1 Kg, 2 Kg, and 5 Kg were 282±11 HV, 269±8 HV, 259±3 HV, 259±2 HV, 256±3 HV, and 254±2 HV, respectively. The hardness value of high strength steel after laser shock peening with 3 J and 10 ns is higher than that treated by 5 J and 20 ns when the load force is larger than 0.5 Kg during microhardness testing, which may be due to that the laser spot with 3 J and 10 ns can induce higher pressure shock wave than that of 5 J and 20 ns in the deeper area. The shock wave is the main factor to enhance the hardness and induce compressive residual stress layer during laser shock peening.

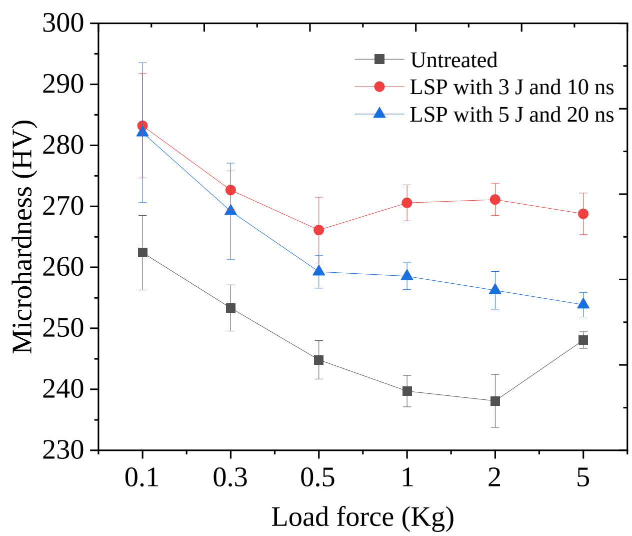

Figure 3. The surface microhardness of steel treated with laser shock peening

The hardness marks were formed during microhardness testing and the size of the mark along the cross-section of the LSPed sample below the surface is smaller compared with the microhardness of the substrate sample at the same position when the depth is less than 800 μm, which is due to the hardness in the top layer (less than 800 μm) of LSPed sample is higher than the untreated sample. Fig. 4 gives the microhardness profiles at different depths, from which it can be found that the thickness of the LSPed layer is less than 900 μm and the laser spot with 3 J and 10 ns can generate higher microhardness than that of 5 J and 20 ns blow the depth of 130 μm. The results show that microhardness in the very top layer (30 μm) does change a lot after laser shock peening and the microhardness in the top layer of 30 μm treated with 5 J and 20 ns is larger slightly than that by 3 J and 10 ns when the microhardness was measured on the cross-section surface.

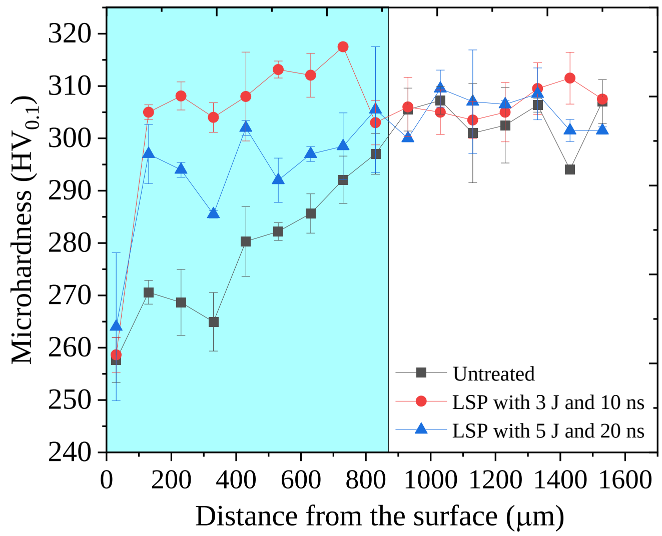

Figure 4. The microhardness along the cross-section of steel with and without laser shock peening treatment.

To study the influence of the LSP process on the residual stress of high strength steel, a hole drilling device (as shown in Fig. 5) was chosen to test its residual stress at different depths. Fig. 6 gives the results of the residual stress of high strength steel at different depths. It could be found that after the LSP process the residual stress can be found below the surface of samples after laser shock peening, which is because of the plastic deformation produced by the high-pressure plasma exposition of the LSP process. The results of residual stress given that the steel sample treated by the LSP process with 3 J and 10 ns has the largest compressive residual stress of 1007.5±110 MPa at the depth of 200 μm when the samples were measured by a hole drilling device to test the residual stress. Residual stress exhibits a distribution similar to microhardness in the top layer of samples treated with 3 J and 5 J for different laser pulse width. When the thickness is less than 130 μm the value of residual stress by 5 J and 20 ns is larger than that by 3 J and 10 ns. when the thickness is deeper the value of fewer than 130 μm the value of residual stress by 5 J and 20 ns is smaller than that by 3 J and 10 ns.

Figure 5. The residual stress device with hole drilling.

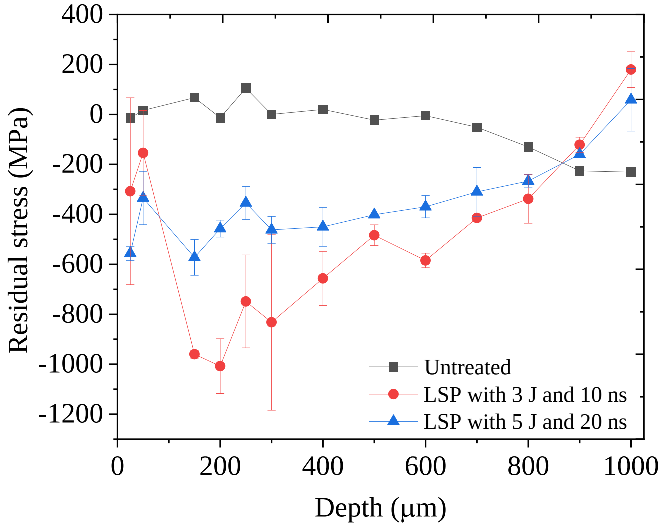

Figure 6. The residual stress at different depths of steel before and after laser shock peening treatment.

4. CONCLUSIONS

The high strength steel was treated by LSP modification with different energy and pulse width during the present research. It can be found that the LSP process with nanosecond laser is an effective method to enhance the microhardness on the surface and at different depth of high strength steel. The laser parameters with laser energy of 3 J and pulse width of 10 ns can induce larger hardness and residual stress than that induced by laser shock peening with 5 J and 20 ns in deeper layer of the high strength steel, which may be due to that the LSP process with 3 J and 10 ns can induce higher pressure shock wave during the process in the deeper layer.

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