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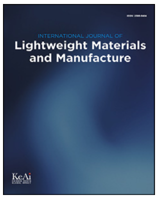

Original Article

The study of laser shock peening with side-water spraying and coaxial-water feeding technology

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The study presents laser shock peening with side-water spraying and coaxial-water feeding technology. Results show that laser shock peening improve the hardness and mechanical property of the 5083Al material through side-water spraying. The protective layer could minimize the ablative damage of laser on the surface of the 2024Al specimen. The laser shock peening technology with coaxial-water feeding was used to treat 5083Al, and it could be obtained that the new laser shock peening method has obviously beneficial results in practical application.

1. Introduction

Laser plays an important role in modern society and has wide application in industry with the rapid development of science and technology [1]. Laser processing, such as laser cutting, laser marking, laser welding, and laser surface treatment, could increase the speed and efficiency of manufacturing. Laser shock peening (LSP), one of the laser surface treatment technologies, is a flexible method of protecting metallic materials from failure in a complex environment [2]. A nanosecond laser system, which could induce high shock pressure, would be used in the technology. When the peak shock pressure exceeds the Hugoniot elastic limit (HEL) of the material [3], it would create plastic deformation on the surface of the material and results in compressive residual stresses. After the treatment, the wear resistance, corrosion resistance and fatigue life of a metallic material could thereby be increased [4].

J. Sheng et al. found that fatigue crack growth rates would be decreased after laser peening process [5]. H. Wang et al. revealed that LSP is an effective method to improve wear resistance in artificial seawater and corrosion resistance of 7075 aluminum alloy in 3.5% NaCl solution [6]. S. Lou et al. verified that nanostructure would be formed in the surface layer with adequate laser shock peening parameters, and more shock impacts or larger laser energy could generate higher grain refinement degree in TC6 titanium alloy and AISI 304 stainless steel [7]. Similarly, Ye et al. studied the microstructures of AISI 4140 stainless steel treated by warm laser shock peening and laser shock peening, and they found that microstructures formed by warm laser shock peening could lead to a higher stability of dislocation structures, which would be beneficial for the fatigue life of AISI 4140 steel [8]. At present, LSP technology is widely used in various fields, such as aviation, mechanical engineering [9]. Solid material or flexible material, such as optical glass and water film, are used as confinement layer in this field. Side-water spraying technology is used during LSP processing when water is used as confinement layer. But side-water spraying technology could not make stable water film on the relatively flat surface of material, and it would lead to water splash when the surface is irregular shape with edges and corners, which could not guarantee the water film thickness.

So, it is very important to develop a new technology to solve this problem. Laser shock peening with coaxial-water feeding technology is a new LSP method, through which the laser beam and the water flow come out in the same direction and the water column is always perpendicular to the surface of material. This paper reports a series of experiments including laser shock peening with and without protective layer by side-water spraying and laser shock peening by coaxial-water feeding technology.

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2. The side-water spraying laser shock peening technology

2.1. Materials and experimental details

5083 aluminum alloy with a thickness of 4 mm and 2024 aluminum alloy with a thickness of 2 mm were used in this experiment. Specimens were polished with silicon carbide emery sheets layer by layer. The principle of laser shock peening with and without protective layer is shown in Fig. 1. A Q-switched Nd:YAG laser system was used in this work, operating at 2 Hz and delivering 0–900 mJ pulse energy with 1064 nm wavelength and 8 ns pulse width. The 5083 aluminum alloy was treated with 8.14 GW/cm^2 and 50% overlap under side-water spraying laser shock peening with protective layer. Water and aluminum foil were used as the confinement layer and protective layer during this experiment. The 2024 aluminum alloy was treated with 7.31 GW/cm^2 and 50% overlap under side-water spraying laser shock peening with and without protective layer. Water and black tape were used as the confinement layer and protective layer. A CMT5105 universal testing machine with the cross-head speed of 1 mm/min was used to test the tensile curve of sample after different LSP treatment.

2.2. 5083 aluminum alloy

After laser shock peening treatment, a VK-X100 K/X200 K confocal laser scanning microscope and a Dino-Lite AM7915 digital microscope were used to characterize the profiles of the elliptic pits and surface topographies on the surface of the 5083Al specimens respectively (shown in Fig. 2 and Fig. 3). Fig. 2(a) shows the 3D morphology of the elliptic pits and Fig. 2(b) shows the 2D profile of the elliptic pits. The dimple depth of the sample is about 15um. This is caused by the plastic flow of the material with the high shock pressure over the Hugoniot elastic limit (HEL) of 5083Al during laser shock peening. Typical surface pictures of the 5083Al specimens with and without LSP treatment are showed in Fig. 3. It can be observed that LSP treatment could change the surface morphology of 5083Al specimens, generating micro-dents and micro-convexities on the surface of 5083Al. The surface roughness parameters of samples with and without LSP treatment would increase from 1um to 4um, which were also measured by the VK-X100 K/X200 K confocal laser scanning microscope.

Fig. 4(a) shows the results of an X-ray diffraction (XRD) profile 5083Al with and without LSP treatment and Fig. 4(b) is the zoomed figure in the 38.1°-38.7°range of 5083Al XRD patterns. It is observed clearly that no additional diffraction peaks could be found after LSP treatment, which suggests that there is no phase transformation and no new crystalline phase emerging during this LSP treatment on the surface of 5083Al sample. What's more, the sample Bragg diffraction peaks after LSP treatment become considerably broader than that of the untreated sample, which may result from the grain refinement or an increase in the atomic level lattice strain on the surface of the untreated sample. Fig. 5 shows the TEM images of microstructure, which was taken in the surface layer from the treated 5083Al alloy after LSP treatment. High density dislocations are found, which indicates that dislocation density could be generated in the top surface layer of 5083Al alloy by LSP. This could be attributed to the multiple plastic deformation of material caused laser shock peening impacts. It could demonstrate that dislocation and plastic deformation could be produced in metallic material under laser shock peening. And the increase of dislocation density induced by multiple LSP treatment is the main reason that increases the microhardness in the surface layer.

Fig. 6 presents the typical microhardness of the sample with single-spot experiment on cross-section of samples untreated and LSP treated respectively. The variation in microhardness profile along the cross section of samples were observed up to the depth about 1200 μm and the microhardness of specimen treated by laser shock peening gradually decreases from the surface, which is due to that the pressure of shockwave induced by LSP. It would decrease along the cross section during the course of impact wave propagation. Fig. 7 shows the typical stress–strain curves of specimens with and without LSP treatment. The tensile strength and yield strength of the untreated specimen are 297 MPa and 242 MPa respectively; The tensile strength and yield strength of the LSP treated specimen are 315 MPa and 276 MPa respectively. The tensile strength and yield strength of 5083Al sample increase by 6.06% and 14.05% after LSP treatment with 8.14 GW/cm^2 and 50% overlap under side-water spraying laser shock peening with protective layer.

2.3. 2024 aluminum alloy

The surface appearance of 2024Al with different LSP parameters is shown in Fig. 8. The surface of specimen becomes rugged when it was LSP treated with protective layer (shown in Fig. 8(a)). There is serious ablation on the surface of 2024Al treated by LSP without protective layer as shown the Fig. 8(c). The surface of specimen would be damaged, which would weaken the LSP treatment effect. So, the protective layer could minimize the ablative damage of laser on the surface of the 2024Al specimen.

Effects of LSP treatment on grain refinement of 2024Al are investigated. Fig. 9 shows the microstructure of specimens before

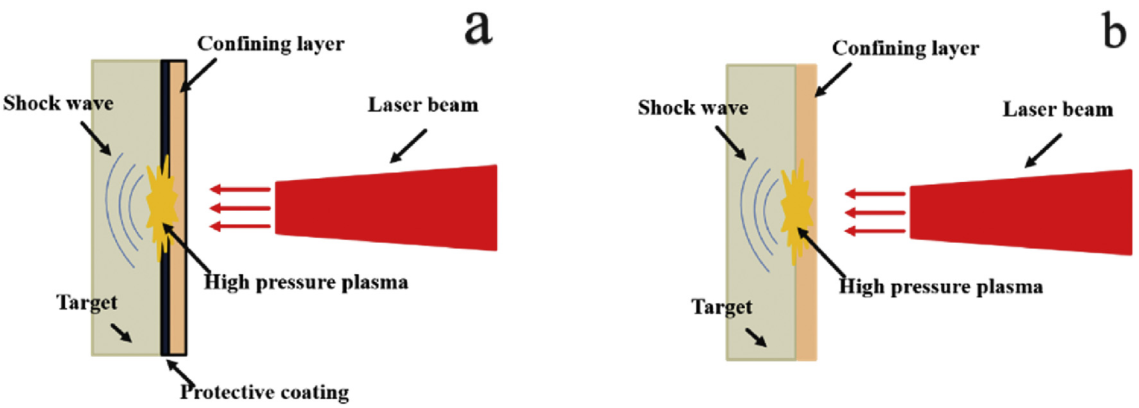

Fig. 1. Schematic and experimental setup of side-water spraying laser shock peening: (a) laser shock peening with protective layer and (b) laser shock peening without protective layer.