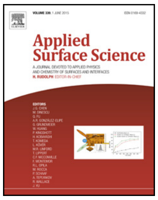
Applied Surface Science 339 (2015) 75–84

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc



Investigation of the crater-like microdefects induced by laser shock processing with aluminum foil as absorbent layer

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ARTICLE INFO

Article history:
Received 1 October 2014
Received in revised form 8 January 2015
Accepted 14 February 2015
Available online 21 February 2015

Keywords:
Laser shock processing
Microdefects
Temperature increase
Aluminum foil
Shock wave

ABSTRACT

This paper reports that 3D crater-like microdefects form on the metal surface when laser shock processing (LSP) is applied. LSP was conducted on pure copper block using the aluminum foil as the absorbent material and water as the confining layer. There existed the bonding material to attach the aluminum foil on the metal target closely. The surface morphologies and metallographs of copper surfaces were characterized with 3D profiler, the optical microscopy (OM) or the scanning electron microscopy (SEM). Temperature increases of metal surface due to LSP were evaluated theoretically. It was found that, when aluminum foil was used as the absorbent material, and if there existed air bubbles in the bonding material, the air temperatures within the bubbles rose rapidly because of the adiabatic compression. So at the locations of the air bubbles, the metal materials melted and micromelting pool formed. Then under the subsequent expanding of the air bubbles, a secondary shock wave was launched against the micromelting pool and produced the crater-like microdefects on the metal surface. The temperature increases due to shock heat and high-speed deformation were not enough to melt the metal target. The temperature increase induced by the adiabatic compression of the air bubbles may also cause the gasification of the metal target. This will also help form the crater-like microdefects. The results of this paper can help to improve the surface quality of a metal target during the application of LSP. In addition, the results provide another method to fabricate 3D crater-like dents on metal surface. This has a potential application in mechanical engineering.

1. Introduction

Since the 1960s, it has been found that when an intense laser irradiates on a metal target, strong shock wave can be launched on the target surface due to the blow-off of the laser-induced high temperature plasma [1,2]. This is especially true in a confined geometry, in which the plasma is confined on the metal surface. In this condition, the peak pressure of the shock wave is more than an order of magnitude greater than that of the direct ablation, and the attenuation time of the shock wave can also be prolonged 2–3 times [3,4]. This strong shock wave can be used to improve the surface performances of metals, which is known as laser shock processing (LSP), one surface treatment method [5–9]. Until now, LSP has been proven effective in improving the fatigue performance [5,6], wear resistance [7,8], and corrosion resistance [8,9] of metal materials. LSP provides these benefits because of the laser shock-induced surface compressive residual stress, and the high density of microstructural defects, such as dislocations and twins. In addition to the strengthening mechanisms of LSP, the various influences of the processing parameters have been widely investigated; these influences include laser wavelength, pulse width, laser beam shape, laser beam size on the metal surface, laser fluence, the confining layers, and the nature of the absorbent layers [10–12]. Presently, we have discovered many important conclusions and laws, which greatly promoted the development of LSP technology.

However, attempts to understand the effect of LSP on the surface quality of the target are relatively limited. When dealing with mechanical parts, fatigue, wear, corrosion and some other types of failures all initiate from the surface materials. Therefore, in addition to the surface hardness and residual stress, surface integrity is another important factor that has a remarkable influence on the quality of the product. Although we ideally hope that the mechanical performances of a laser-shock-processed (LSP'd) target will be improved without deteriorating its surface quality,

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http://dx.doi.org/10.1016/j.apsusc.2015.02.111

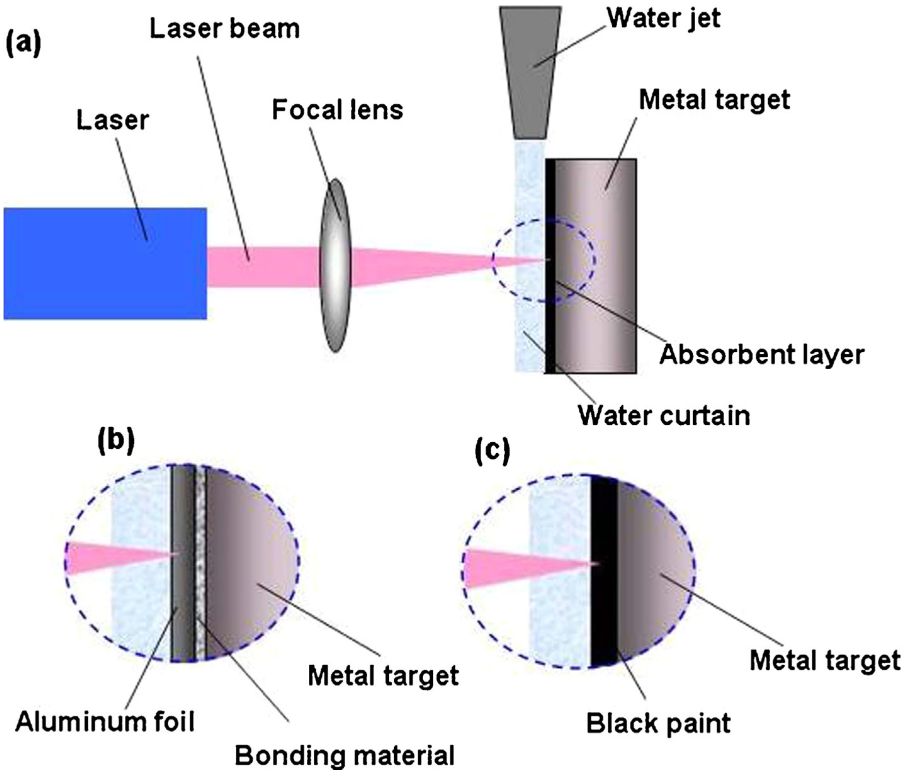

Fig. 1. The schematic of the experimental setup.

the status of the surface do will be changed. As is well known, laser shock processing will create macropits on target surfaces, just as shot peening [13–16]. In recent years, some researchers have even used LSP to fabricate functional microdents on metal surfaces to improve the lubrication between friction pairs. This is done because the dents produced by LSP can act as lubricant oil reservoirs [15,16]. The result is just like that of the conventional laser surface texturing technique [17,18], which produces microdimples on a target surface through laser ablation. Additionally, laser shock processing also can change the surface roughness of metal targets [13,19,20]. About this problem, we note that some researchers have found that LSP can deteriorate the surface roughness [19], while some others have found that the roughness could be improved [13,20]. Generally, not enough researches have been conducted on the surface states of LSP'd parts. Many important problems, such as how LSP influences the surface states of the parts, and how to control their surface qualities, are still pending. All these problems cannot be bypassed for the actual engineering applications.

In this article, we conducted the LSP experiment. The target was pure copper blocks. After the application of LSP, macropits, and also some crater-like surface defects with the dimensions of several tens to hundreds of micrometers were observed on the shocked zones. This phenomenon is novel. We investigated the forming mechanisms of these surface defects by characterizing the surface morphologies using a 3D profiler, the optical microscopy (OM), and the scanning electron microscopy (SEM). Also, the temperature increase of the metal surface during laser shock processing were evaluated, to further elucidate the experimental results. We believe the results may be helpful for improving the LSP technique, and may provide guidance for developing an appropriate process to control the surface quality of LSP'd targets.

2. Experimental procedures

2.1. Sample preparation

Before applying LSP, pure copper blocks with the dimensions of 25 mm × 25 mm × 5 mm were mechanically polished firstly, then ultrasonically cleaned in ethanol and finally dried in air. Thereafter, all specimens were annealed in the a vacuum, so as to facilitate the observation of the microstructural changes before and after LSP.

2.2. Laser shock processing

The schematics of the experimental setup are shown in Fig. 1. All laser shock experiments were performed using one flash lamp-pumped Nd^{3+}:YAG laser (GAIA R) from the Thales Company. The central wavelength of the laser is 1064 nm, the maximum available energy is 13 J, and the pulse duration is about 15 ns. The spatial energy distribution of the output laser beam is nearly flat-top. This laser can operate in single-shot mode or repetition mode. Under the latter mode, the repetition rate of the laser can be adjusted between 1–5 Hz. During our experiment, we only used single-shot mode for conveniently controlling the impacting times, and all specimens were impacted one time at one point. The output laser was focused onto the metal surface using a focusing lens with the focal length of 1.5 m. Then the laser beam diameters on the specimen surface were approximately 2 mm.

Water curtain with the thickness of 2 mm flowed on the target surface to confine the expanding plasma, in order to increase the peak pressure of the shock wave and delay its attenuation.

In our experiments, aluminum foil was mainly used as the absorbent material. First, we conducted LSP using industrial aluminum foil tape as the absorbent layer. This aluminum foil tape is composed of pure aluminum foil (with a thickness of approximately