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The research of micro pattern transferring on metallic foil via micro-energy ultraviolet pulse laser shock

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ABSTRACT

A micro-energy high frequency ultraviolet pulse laser was introduced for fabricating the micro pattern on pure aluminum foil by laser shock transferring. The copper mesh mold (mesh size: 400# and 1000#) and pure aluminum foil were used to investigate the effect of laser pulse energy and overlap ratio on micro pattern transferring. A FEM model was adopted to simulate the aluminum foil deformation and plastic strain in laser shock process. To investigate the micro forming mechanism of laser shock transferring, the micro morphology of significant area on processed micro pattern was observed by atomic force microscope (AFM). The experimental results revealed that the depth of transferred micro pattern increased with the increasing of single pulse energy and overlap ratio within certain range. The forming depth of aluminum foil imprinted from 400# mold was larger than that of 1000#, and more sensitive to pulse energy and overlap ratio. The aluminum foil on mold bars was smoother than that of on mold holes. The study demonstrated that the micro-energy ultraviolet pulse laser shock can realize the precise, controllable, fast and ultrahigh strain rate fabrication of surface microstructure.

1. Introduction

The rapidly developed MEMS and increasing sophisticated and precise micro-device fabrication have been put forward more requirement for new machining techniques that distinguished from traditional manufacturing methods. Laser shock peening is a competitive micro manufacturing technique which has been widely used in various processes, such as sheet metal bending forming [1], metal surface plastic deformation [2], laser shock induced surface modification to prolong work piece fatigue life [3], laser dynamic flexible forming [4], laser punching [5] and laser shock imprinting [6]. For laser shock imprinting, laser induced high pressure shock wave was used to transferred microstructure pattern on metallic foil. Compared with lithography [7], mechanical micro-machining, electrolytic machining [8] and ablation machining [9], it has a hug advantages due to its high efficiency, no thermal effect, and ultrahigh strain rate and direct shaping.

Many scholars have investigated laser shock imprinting in different aspects. Liu et al. take an infrared laser (laser diameter 3 mm, pulse energy 350 mJ, 750 mJ, 1400 mJ, wavelength 1064 nm) to investigated the influence of copper foil grain size and micro-mold size on forming depth and revealed the forming mechanism in laser shock flexible drawing [10]. M. Morales concentrated on the influence of plasma confinement and multiple pulses on laser shock micro informing of thin metal sheets (pulse energy 21 mJ, wavelength 1064 nm) [11]. Zheng et al. observed the morphology and deformation depth of pure copper processed by confining layer (quartz glass) with different thickness, which revealed the confining layer thickness has significant influence in micro scale laser bulge forming (pulse energy 450 mJ and wavelength 1064 nm, laser diameter 0.6–0.9 mm) [12]. Shen et al. fabricated micro rectangle array with dimensions of 500 × 450 × 14 μm on aluminum foil surface by laser (pulse energy 850 mJ, infrared laser, laser diameter 4 mm) shock embossing, and large area three-dimension array can be obtained on metallic foil [13]. Wang et al. studied microscale laser shock (pulse energy 835 mJ, 1200 mJ, 1550 mJ, 1800 mJ, wavelength 1064 nm, infrared laser, mold size 800 μm) dynamic flexible forming from accuracy, depth, thickness thinning ratio, and surface quality, and revealed that microscale laser shock dynamic flexible forming can relieve localized necking, stress concentration and roughness of formed surfaces effectively [4]. Ye et al., using a laser beam with wavelength 1064 nm, pulse energy 106 mJ, patterned micro-texture (6.5 μm) on memory alloy surface by laser shock direct imprinting, and proved that the shaping method does not require sharp mold, nor does it involve any heating or etching process [6]. Gao et al. fabricated large-scale

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uniform nanostructure (as small as 10 nm and aspect ratio 5) on aluminum foil by laser shock imprinting, and presented a new method for fabricating nanodevices [14]. However, almost current researches about laser shock imprinting adopt infrared pulse laser (wavelength was 1064 nm, beam diameter was on the scale of millimeters, pulse energy ranges from several hundreds of micro joule to several joule). In addition, all these studies employed infrared laser pulse with about tens of Hz, except that Wenwu Zhang investigated laser shock peening with high frequency (1000 Hz) ultraviolet laser [15]. Extremely thin metallic film was often used in medical inspection and mass spectrum analysis [16]. However, the infrared high-energy laser used in previous studies was not suitable for preparing microstructures in micro-area. The laser power density was extremely high when large-scale laser focused on microscale spot (several to dozens of μm), and the excessive power density would destroy the confining layer and affect the imprinting equality of material surface. The laser power density was in a reasonable range when micro-energy pulse laser focused on microscale (several to dozens of μm). By adjusting microscale laser parameters, the best laser shock transferred microstructures can be obtained on material surface. Microscale pulse laser can also shock different micro regions of material surface flexibly. Compared with the uneven energy distribution of laser with large spot, the microscale laser can make the shock energy distribution more uniform and obtain precise surface microstructures [17,18]. Therefore, the micro-energy pulse laser with microscale spot has more potential in fabricating microstructure and precise micro-devices because of low single pulse energy and small beam size.

Overall, systematic research related to high frequency, micro pulse energy, ultraviolet laser with micro-scale laser spot in laser shock imprinting are still rarely. We reported the experimental and numerical simulation results of laser shock transferring on aluminum foil, which adopted ultraviolet laser with maximum pulse energy 150 μJ, frequency 1000 Hz, beam diameter 20 μm and wavelength 355 nm. The influence of overlap ratio and pulse energy was investigated in experimental work. A FEM model was used to simulate the deformation process and plastic strain distribution of aluminum foil surface. The local morphology of single square micro pattern was observed to investigate the micro forming mechanism.

2. Experimental work

The Fig. 1 shows the schematic of laser shock transferring. The experiments in this paper were carried out using a Q-switched Nd: YAG laser (DSH-355-10, PHOTONICS INDUSTRIES, USA) operating at 1000 Hz with the wavelength of 355 nm, laser beam diameter of 20 μm, the pulse duration of 10 ns and the maximum single laser pulse energy is 1 mJ. The laser beam was incident to a computer controlled galvo scanner, which can control the fast movement of pulse laser beam. On a single line, the adjacent laser spot distance d_1 can be obtained by adjusting laser scanning speed. The scanning line pitch d_2 can be set in laser marking software. In laser shock scanning process, the different laser overlap ratio can be obtained when scanning line pitch d_2 was same as the laser spot distance d_1.

Aluminum with good mechanical properties has extensive application in various fields. The material of laser shock micro pattern transferring specimens was a 10 μm thick pure aluminum foil (99.9%) which was also used as absorbing layer to avoid the specimens being ablation. In Fig. 2(a), the original aluminum foil surface distributed many irregular and rough stripe structures. The confining layer was a K9 glass with thickness of 2 mm. The sizes of 400# (hole size: 37 μm; bar width: 25 μm; thickness: 15 μm; diameter: 3 mm) and 1000# (hole size: 19 μm; bar width: 6 μm; thickness: 10 μm; diameter: 3 mm) transmission electron microscope (TEM) copper mesh were selected as mold. The copper mesh surface was completely scanned by pulse laser. Fig. 2 shows the scanning electron microscope (SEM) images of the original morphology of aluminum foil and copper mold. The smooth table provided a very smooth work plane in the process of transferring the regular structures of copper mold to aluminum foil surface. As shown in Fig. 1, ensuring without any gaps, the holder provided a preload to clamp the glasses, aluminum foil and mold. All the aluminum foil and copper mold used in the experiments were cleaned in alcohol by ultrasonic. The different laser parameters manufactured micro-scale structures on aluminum foil surface was monitored by different analytical apparatuses. The surface morphology of specimens was observed by SEM (Quanta TM 250; FEI, USA) and ultra-depth three-dimensional microscope (VHX-1000; KEYENCE; Japan). A Leica optical (DM4M) microscope was used to research the morphology of K9 glass and aluminum foil surface. The local morphology of transferred square micro pattern was investigated by a commercially available AFM (CSPM5500; Benyuan Nano-Instrument, China).

As shown in Fig. 1, during the laser shock transferring process, the laser pulse penetrated the confining layer to irradiate the absorbing layer, vaporized the absorbing layer and produces high pressure plasma instantaneously. Under the constraint of confining layer, the plasma exploded and generated a ultra-short duration shock wave which expanding into the aluminum foil. The peak pressure of shock wave reached several GPa which far exceeded the dynamic yield strength and induced plastic deformation of aluminum foil.

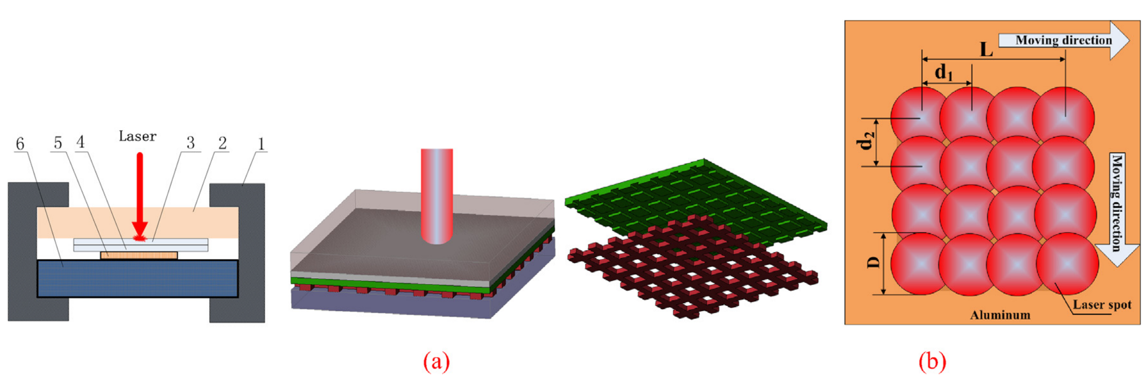

Fig. 1. (a) The schematic of laser shock transferring and the forming process (1. holder, 2. confining layer, 3. absorbing layer, 4. specimen, 5. mold, 6. smooth table), (b) Schematic of laser spot overlapping rate.