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Investigation on bend displacement and surface quality induced by laser shock micro-adjustment

Chunxing Gu[1], Zongbao Shen*,[1], Huixia Liu, Pin Li, Mengmeng Lu, Qiang Zhang, Xiao Wang

School of Mechanical Engineering, Jiangsu University, Xuefu Road, Zhengjiang 212013, China

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ABSTRACT

Laser shock micro-adjustment is a new adjustment technique using laser-shock-waves to adjust the curvature of micro-components (micro-mechanical cantilevers). A full empirical study has been conducted, with the effects of laser energy, laser shock region and sample thickness investigated. And, the influences of laser processing parameters on the surface qualities are also taken into consideration and investigated. According to the result, compared with the surface roughness in the shock and un-shock regions, it can be found that the average surface roughness (R_a) of adjustment surface is lower than that of other un-shock surface, implying the surface quality would be upgraded via the shock micro-adjustment processing. A fine surface quality can be obtained by means of adjusting the laser parameters and the thickness of coating, as well as other process details. Such a technique is simple to implement, yet very useful for applications involving adjustment of micro-components in the field of MEMS.

1. Introduction

The increasing demands in MEMS fabrication are leading to new requirements in production technology [1–3], especially adjustment of the micro-components, such as micro-mechanical cantilevers, which is widely used as extremely sensitive physical, chemical, and biological sensors [4–7], require high accuracy in positioning, high reproducibility and low production costs. Meeting these demands is still an up-to-date key assignment in micro-manufacturing. Since the traditional mechanical adjustment technologies are failed to meet the requirement for their un-ideal accuracy and time consuming by mechanical forces or dynamic impact forces [8]. There is a need for a precise and contact-free adjustment technology to control the bending angles of some micro-mechanical cantilevers. Laser based micro-adjustment offers the potential to achieve this.

Laser thermal adjustment, known as a non-contact technique utilizing laser-induced thermal effect to shape melt sample without tooling or external forces, is an example of this [9]. The technique is regarded as the temperature field and deformation field interaction process which producing a residual strain over the surface of the cantilever material caused by the temperature gradient [10]. When laser beam irradiates the target surface, the workpiece surface is heated and produces a non-uniform temperature field in the thickness direction. The generated thermal stress is used to achieve plastic deformation such as the bending deformation [11,12]. By changing the laser processing parameters, different bending angles are obtained to adjust curvature of the micro-cantilevers. The previous works show that there are three common forming mechanisms, Temperature gradient mechanism (TGM), Buckling mechanism (BM), Upsetting mechanism (UM), respectively [13–15].

However, due to the thermal forming mechanisms are determined by the temperature field induced by laser which is influenced by the geometry of workpiece, laser power, laser beam diameter, scanning velocity, scanning path, etc., it makes the bending direction uncertain and become a hard controlled process for forming complex shapes and high precision curvature modification [16]. In addition, the thermal effect will result in undesirable microstructure change including recrystallization and phase transformation even without melting involved during the process [17]. Also, it may melt or burn the surface and even result in small cracks on the surface [18]. Therefore, it is hard for laser thermal forming to maintain material properties of bended cantilevers.

Laser shock micro-adjustment is a new adjustment technique using laser-shock-waves to adjust the curvature of micro-components (micro-mechanical cantilevers). The application of laser-shock-waves on thin sheet metal has received more and more attentions [19,20]. It is regarded as a purely mechanical forming method achieved through the laser induced shock waves. It has the advantages of laser thermal forming, such as noncontact, tool-free and high efficiency. In addition, its non-thermal character makes it possible to maintain material properties or even improve them through the induction of residual stress over the target surface,

* Corresponding author. Tel.: +86 051188797998.
E-mail address: szb@ujs.edu.cn (Z. Shen).
[1] [1]contributed equally to this work.

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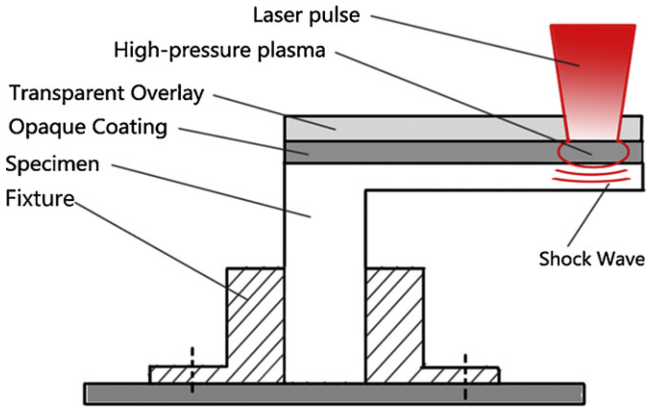

Fig. 1. Schematic of laser shock micro-adjustment.

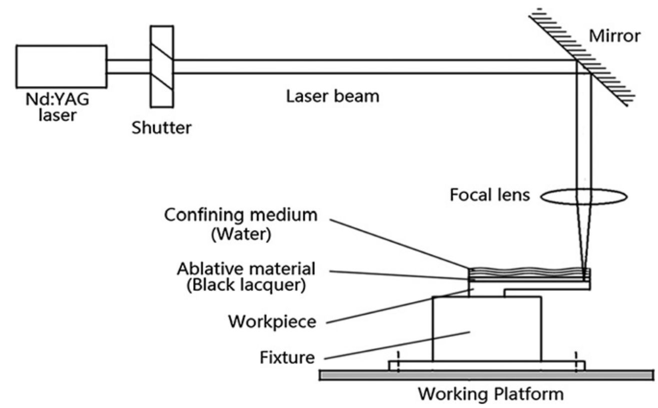

Fig. 2. The layout of experiment.

which is desirable because it is important in industry for shaped target to keep corrosion and fatigue from generating cracks [18–21]. The laser-shock-wave induced thin sheet metal bending trends are similar to traditional shot peen forming studied by Kopp and Schulz [22]. Therefore, laser shock micro-adjustment is simple to implement, yet very useful for high-precision curvature adjustment. As such it has potential for widespread application in both the manufacturing and microelectronics industry.

In the present paper, a series of laser shock micro-adjustment experiments were conducted along with the influences of the laser energy, laser shock region and sample thickness on the amount of bending deformation and surface quality. According to the result, compared with the surface roughness in the shock and un-shock regions, it can be found that the average surface roughness (R_a) of adjustment surface is lower than that of other un-shock surface, implying the surface quality would be upgraded via the shock micro-adjustment processing. Besides, the micro-craters generated in the shock surface of the target were also observed and measured to evaluate the surface quality. The resulting surface of the target has no sign of damage, owning the quite good surface quality.

2. Adjustment mechanism

As illustrated in Fig. 1, the typical application of laser shock micro-adjustment process is carried out under a confined regime configuration. The target surface is first locally coated with an opaque coating and then covered by a transparent overlay; the dielectric material transparent to the laser beam such as water. When a high-energy focused and pulsed laser beam is irradiated onto workpiece surface, the coating is instantaneously vaporized into a high-temperature and high-pressure plasma. This ablated plasma expands from the workpiece surface and, in turn, exerts mechanical pressure on the workpiece surface, which induces compressive waves in the workpiece. The opaque coating acts as the sacrificial material to avoid the thermal effect from heating the surface by the short pulsed laser irradiation, the transparent overlay delays the thermally expansion and confines plasma against the surface of target material, thus generating higher pressure [23]. Since the sample was made in cantilevers-shape with a free side and a fixed side showed by Fig. 1, the laser beam is irradiating the free side of the sample, the downward shock loading imparts a downward inertia to the shocked region, this downward movement continues due to the inertia during relaxation to make the shocked region plastically deformed. And, the local plastic deformation induced in the shocked region would make the tensile material flow to plastically deform workpiece curved and generate bending deformation. The forming behavior can be compared to that of some high energy rate forming process. So we can control the forming degree by adjustment of the laser energy [16].

3. Experiment

3.1. Experiment instruments and preparation

For experiments, a short pulse Nd-YAG laser with Gaussian distribution beam is used. It is operated at the repetition frequency of 10 Hz and the pulse duration about 8 ns. The wavelength of 1064 nm is selected to enable the laser beam to propagate longer through water with lower absorption of beam energy. The laser pulse is conducted to the interaction area by means of a reflecting mirror and a focusing lens (f = 100 mm), as shown in Fig. 2. In order to get the desired spot size, the work piece is placed away from the focus at the right distance.

Fig. 3 shows the shape and size of specimen. The method of wire-electrode cutting was employed for cutting. And, the tolerance of cutting was ±0.02 mm. The sample which was cut to cantilever-shape from commercially supplied Aluminum (1060 of 99.6% purity) sheets is used as the target. Anhydrous alcohol was adopted to clean the surface of work piece, and the smoothness of workpiece should be guaranteed by polishing. In order to improve the material's absorptivity to the laser during micro-adjustment process, the sample should be generally coated with black lacquer. And water is used as the transparent overlay to confine the generated plasma. To ensure that the sample space position, a special

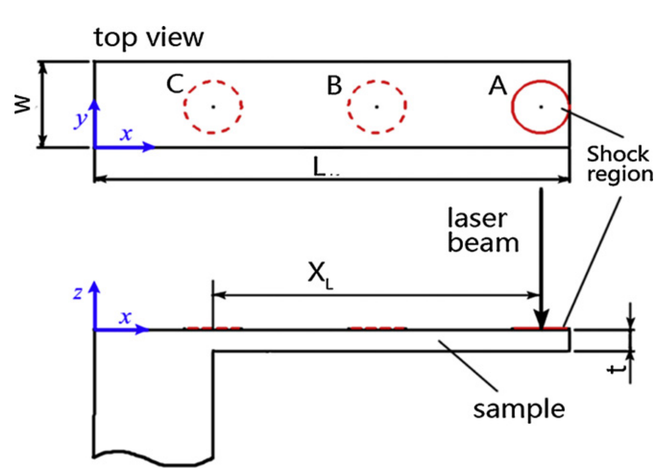

Fig. 3. Schematic of workpiece (material: Al; dimension: the width W, the length L, the thickness t; shock region: A, B, C).