FABRICATION OF MICROSCALE FEATURES THROUGH THE BALLISTIC IMPACT OF A METALLIC HYPERVELOCITY FLYER

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Abstract— Microstructures such as microscale holes and grooves are increasingly needed in various industrial fields. In this study, a metallic thin flyer was accelerated by a high-power pulsed laser, and used as a high-pressure medium of dynamic loading to fabricate microscale structures. In order to find the fundamental understandings of this process, the flyer velocity resulting from laser interactions was predicted using the Gurney theory. In addition, a series of microscale punching process which has a wide range of application in microfluidic and electrical devices, was carried out to validate the performance of the process.

Keywords— Pulsed laser, Hypervelocity, Microfluidic device, Metallic flyer

I. INTRODUCTION

With the rapid development of biotechnology, solar cells, electronics, and micro-electromechanical system (MEMS) industries, microscale metallic devices are becoming more and more important and increasingly demanded [1]. The high velocity dynamic loading technique utilizing a pulsed laser has many potential advantages when compared to the conventional fabrication techniques [2]. These include low cost, high efficiency, one-sided tooling, and high formability of high-strength or hard shaping materials [3].

In order to obtain the fundamental understandings of the process, the flyer velocity resulting from laser interactions was predicted using the Gurney theory. In addition, a series of microscale punching process which has a wide range of application in microfluidic and electrical devices, was carried out to validate the performance of the process.

II. METHOD

Fig.1 shows the experimental set-up for the ballistic impact system. A Q-switched Nd-Yag laser (maximum pulse energy: 2J, wavelength: 1064nm, pulse duration: 10ns), reflecting mirrors and a focusing lens were used to irradiate the intense laser pulse on the flyer surface. As illustrated in Fig. 2, the laser energy vaporizes the flyer surface instantaneously, and generate a high-temperature and high-pressure plasma. This plasma absorbs the laser energy and accelerates
the remaining metallic flyer. The accelerated metallic flyer impacts the workpiece at hypervelocity and makes the workpiece deform into the mold cavities. Spacer and hyper-elastic material were inserted between the confinement layer and workpiece to secure the flying distance of a flyer and protect the workpiece surface from the laser-induced plasma.

![Figure 1. Experimental set-up for the ballistic impact system](image)

**Figure 1.** Experimental set-up for the ballistic impact system

**Figure 2.** High-velocity and high-pressure dynamic loading mechanism for microscale material deformation.

**III. RESULTS**

For the theoretical analysis, a circular aluminium flyer of 2mm diameter and 20μm thickness was used. Carbon layer of 10μm thickness was coated onto the upper surface of the flyer to reduce the energy loss of laser by reflection. The amount of laser energy $e(x)$ absorbed by the metallic flyer can be approximated by the following:

$$e(x) = \mu_{\text{eff}} I_0 (1 - r) \exp[-\mu_{\text{eff}} x_d]$$

where $I_0$ is the energy density, $r$ reflectivity, $x_d$ the ablation depth, and $\mu_{\text{eff}}$ effective absorption coefficient.

Using the Gurney theory [4], the average velocity of the flyer can be calculated using the following equation:

$$v = \sqrt{\frac{6 \rho_f x_f E}{3 \rho_f x_f + \rho_d (3x_0 - 2x_d)}}$$

**Figure 3.** Velocity of the flyer vs. laser intensity estimated using the Gurney Theory.

The preliminary experimental results were also shown in Fig. 4. 300μm and 500μm holes were successfully fabricated both in 50μm and 100μm workpieces.

**IV. CONCLUSIONS**

A laser-induced dynamic loading technique is utilized to fabricate microscale features in metallic materials. The flyer velocity was estimated using the Gurney
theory. The fabrication performance of this process was validated through a series of experimental work.

Figure 4. Experimental results for the fabrication of 300μm and 500μm holes at different thicknesses.

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