

## **Laser shock forming of 3D profiles on a copper foil without the assist of a master mould**

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### **Abstract**

The study investigated laser dynamic forming on copper foils using a silicone rubber as a flexible support without the assist of a master mould. A nanosecond pulsed Nd:YAG laser was used to ablate an overlay layer on the copper foil, in which shock waves were produced causing controlled deformation of the copper foil. Spherical craters with varying depths and radius were formed on the copper foil by changing laser fluence. The grain structure of the deformed region was studied using Electron Backscatter Diffraction Analysis (EBSD).

### **1. Introduction**

Laser-induced shock waves cause plastic deformation in a metal foil with the formed profile conforming to a master mould placed underneath the foil. This process is called laser dynamic forming. Studies have shown that the geometry of the formed features depends not only on the mould geometry but also on the laser process parameters such as the laser fluence, spot size, and the number of pulses [1]. As mould fabrication is costly, industries would prefer a method of forming micro features on metal foil without a master mould. This study focuses on formation of 3D profiles on metal foils without the assist of a master mould.

### **2. Experimental**

Figure 1 shows the schematic setup. A 25 µm-thick copper foil was used for 3D profile formation. A Q-switched Nd:YAG laser with wavelength of 1.064 µm, pulse width of 38 ns, and maximum pulse energy of 75 mJ at 6 KHz was used for laser

ablation. The laser beam was 0.6 mm × 0.6 mm in square after a 80 mm focal lens. A 15 μm-thick Al-foil was used as the ablative overlay due to its low vaporization threshold. Furthermore, Al-foil is peeled off more easily from the deformed foil surface as compared to other ablative materials such as paint coating and black tape. Deionized water was used as the confinement layer. The entire setup was placed in a container filled with water about 4.0 mm above the copper foil. A 0.3 mm-thick silicone rubber was used as the flexible pad against which the foil deformation occurred. Only one laser pulse was applied in all laser experiments.

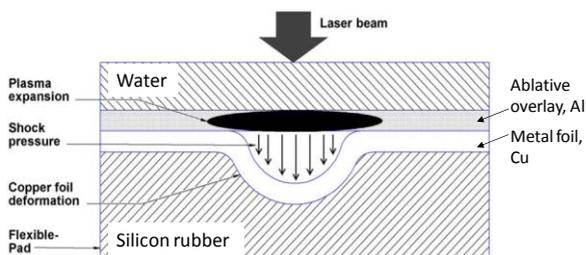


Figure 1: Schematic setup of the flexible pad laser shock forming (FPLSF)

### 3. Results and disussion

#### 3.1 Formation of craters

Figures 2a and 2b are the typical SEM images of the top and bottom surface of the formed crater. The deformation depth and diameter of the formed crater were characterized by the bulge height ( $h$ ) and bulge diameter ( $D_b$ ) as indicated in Figure 2e. Maximum deformation depth was observed at the center of the crater. The laser-induced shock loading  $P$  is expressed according to Fabbro's model [2]:

$$P \text{ (GPa)} = 0.01 \sqrt{\frac{\alpha}{3 + 2\alpha}} \sqrt{I_0 \text{ (GW/cm}^2\text{)} Z \text{ (g/cm}^2\text{s)}}$$

, where  $\alpha$  is the fraction of internal energy used to increase the plasma thermal energy.  $I_0$  is the laser intensity and  $Z$  is the shock impedance that is calculated by  $2/Z = 1/Z_1 + 1/Z_2$ , in which  $Z_1$  and  $Z_2$  are shock impedances of target and confinement materials respectively. The peak shock pressure calculated from Fabbro's model for laser fluence of 13.6 J/cm<sup>2</sup> was 0.58 GPa whereas  $\alpha = 0.1$ ,  $Z_1 \text{ (Al)} = 1.5 \times 10^6 \text{ g cm}^{-2} \text{ s}^{-1}$  and  $Z_2 \text{ (Water)} = 0.165 \times 10^6 \text{ g}$

$\text{cm}^{-2} \text{s}^{-1}$  [3]. Thus, the shock force loading could be controlled accordingly by adjusting the laser fluence for achieving various craters on the copper foil.

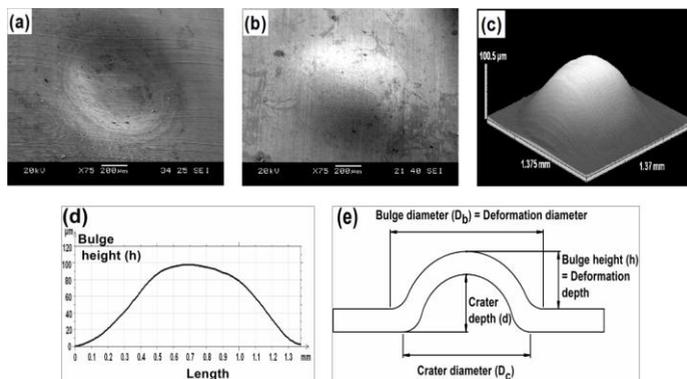


Figure 2: Crater formed on copper foil at laser fluence of  $13.6 \text{ J/cm}^2$ . (a) SEM image of top surface, (b) SEM image of bottom surface, (c) Topography of the crater by the stylus profilometer, (d) Cross-sectional profile, (e) Method to measure the deformation depth and diameter.

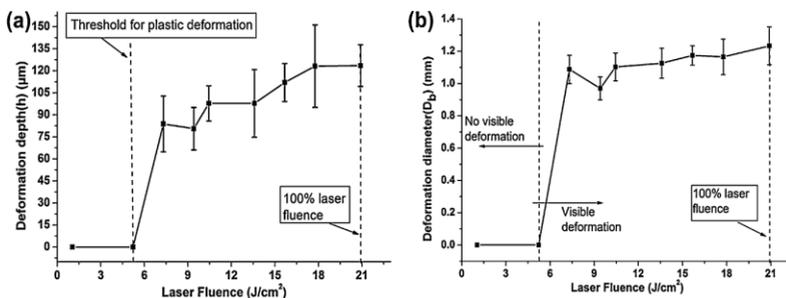


Figure 3: Influence of laser fluence on the geometry of craters formed on copper foil

It appears that there existed a fluence threshold at about  $5.2 \text{ J/cm}^2$  for the copper foil, below which the laser-induced shockwave pressure was lower than the dynamic yield strength of copper (peak pressure was 0.42 GPa for  $5.2 \text{ J/cm}^2$  according to Fabbro's model). No plastic deformation was observed due to: (i) Laser fluence was insufficient to ablate the AL-foil, resulting in no plasma and shockwave formation. (ii) Ablation of AL-foil was limited to a small volume at the top portion of Al-foil. The propagating shockwave was attenuated in the remaining thickness of the Al-foil.

Above the threshold, the deformation depth increased with the laser fluence largely due to the increase in shock pressure exerted on the copper foil.

### 3.2 Change in microstructure

EBSD analysis showed that a misorientation angle above  $10^\circ$  in crystal structure was observed in the deformation region of the foil. The grains became refined and more uniform as shown in Fig. 4. About 60% of grain sizes are in 1.5-2.0  $\mu\text{m}$  band. The Hardness Vicker (HV) value measured before and after the laser shock process is HV34.7 and HV50.0 respectively. In other words, nearly 50% increase in HV was obtained by laser shock hardening.

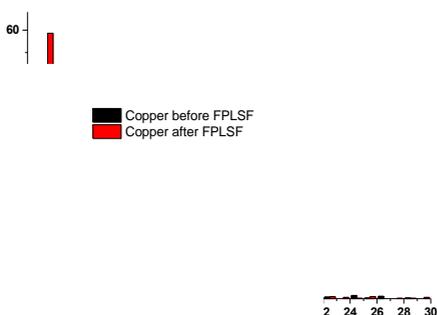


Figure 4: Grain size distribution under laser shock of  $20.9 \text{ J/cm}^2$

## 4. Conclusion

Short pulse Nd:YAG laser has been demonstrated to form spherical craters on a copper foil with deformation depths of  $80 \mu\text{m}$  to  $130 \mu\text{m}$  and radius of  $485 \mu\text{m}$  to  $616 \mu\text{m}$  when the laser fluence varied from  $7.3 \text{ J/cm}^2$  to  $20.9 \text{ J/cm}^2$ . EBSD analysis revealed that the grain became refined and more uniform in the deformed region. The plastic deformation led to an increase in hardness by more than 50%. The method is potentially used for forming 3D profiles. Future work will focus on reducing the size of the craters and improving process consistency.

## References:

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