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Micro bulging of thin T2 copper sheet by electromagnetic forming

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Abstract: Electromagnetic micro bulging experiments on T2 copper were achieved in order to find the effects that different voltages and depths of mold work on deformation characters. Laser scanning confocal microscope and contourgraph were used to study the effects of electromagnetic forming parameters such as voltage and die depth on material. Results show that width and depth of micro channel increase with the increases of voltage with a certain die depth, moreover, forming depth reaches the maximum at 7 500 V. And then rebound emerges and forming depth decreases. Forming depth and width of channel increase with the decease of die depth at a certain voltage; and forming depth reaches maximum at 0.5 mm of die depth. Therefore, rebound is weakened and the traces caused by bad exhaust disappears gradually, and surface roughness decreases simultaneously in electromagnetic bulging experiments.
Key words: sheet; micro-forming; micro bulging; electromagnetic forming

1 Introduction

In recent years, metal foil and metal thin-walled parts have been widely used in microelectronics and MEMS (Micro electromechanical system) products. There is a great interest from research institutions in micro-formation of sheet due to rapid development of MEMS technology and electronic industry [1−5]. However, feature size from macro level to micro level has been changed, and the properties of material have also undergone a significant change. There are three main types of change: 1) changes of flow stress in material; 2) changes from isotropic of material in macro level to anisotropy of material in micro level; 3) changes of plasticity, forming limit and extension in forming parts. So, it is the key technology to improve plasticity in micro forming [6−7]. Electromagnetic forming with high energy has a metal deformation speed which is up to 200 m/s and gives a special performance to material in deformation process. Forming process makes material to show high plasticity and extension, and the die fitness has been improved. Electromagnetic force is able to produce uniform forming force which can weaken rebound. Electromagnetic forming process is easily controlled and reproduced. In addition, electromagnetic is a non-contact process which can extend the mold service life without oil, so the electromagnetic forming process of sheet metal used in micro-forming was expected to solve many existing problems [8−10]. Electromagnetic micro forming will be widely used in mass production of micro parts with less cost. KAMALA et al [11] achieved rapid manufacturing by two-step method in electromagnetic forming micro box-shaped pieces. HOCHENG and WEN [12] studied stamp forming assisted by electromagnetic force in sub-micro structures experiments, and there were no defects and distortions in the forming parts. This way of deformation reduces the rebound and is more flexible. Compared with the traditional method, the design, manufacture and repair of mold are simple. ZHANG et al [13−15] independently developed a set of micro-electromagnetic forming device in order to study sub-micron micro-volume forming part, and simulated compression and pressure using ANSYS finite element software. The results showed that the increased processing speed could significantly reduce the friction coefficient and the size effect had been weakened. Micro bulging of sheet deformation was carried out by electromagnetic micro forming experiments, and effects of working voltage and mold depth on parts were studied while the effects on the organization of material from electromagnetic force were also analyzed in this work.

2 Experimental

Experimental device was adopted for electromagnetic forming with 20 kW power. The capacitance and voltage

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of device were 100 μF and 20 kV, respectively. The cross section of part is shown in Fig. 1. The geometric dimensions of part include five channels, and the channel depth, channel width and rib width are 0.6 mm, 1.5 mm and 2 mm, respectively.

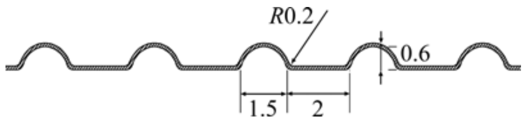

Fig. 1 Profile of parts (Unit: mm)

The T2 copper sheet with thickness of 0.1 mm was selected for metal sheet deformation. Induction forming was carried out in this experiment. Copper sheet with thickness of 0.16 mm annealed for 2 h at 650 °C was used for dive vane. The experiment device is shown in Fig. 2.

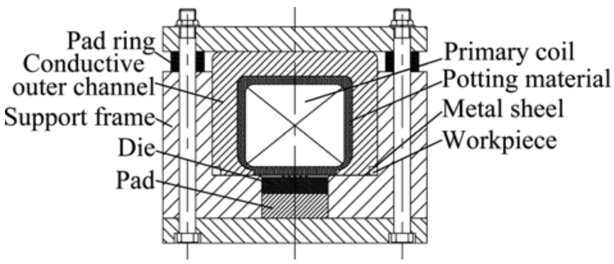

Fig. 2 Electromagnetic forming device

3 Results and discussion

3.1 Effect of voltage on deformation

During this test, the electric capacity and mold depth were 100 μF and 3 mm, respectively. The test voltages were 1 400, 6 000, 7 500 and 9 000 V, respectively. And a cross section was measured by laser scanning confocal microscope and contourgraph. Figures 3 and 4 show the sectional drawings of charnels at different voltages.

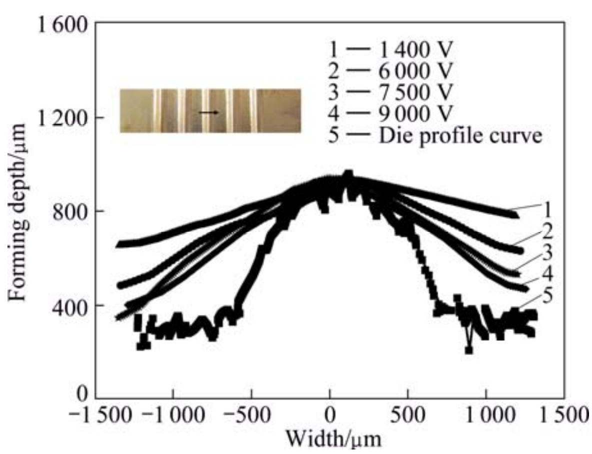

Fig. 3 Sectional drawing of single channel at different voltages

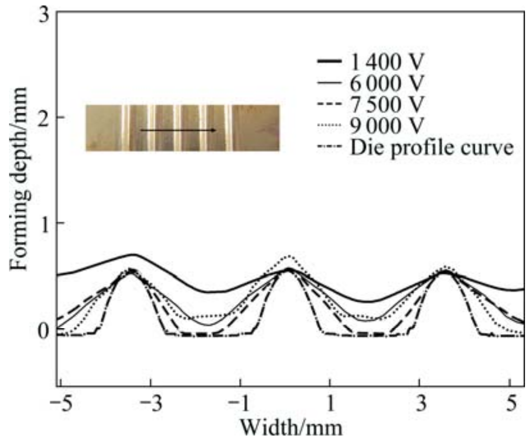

Fig. 4 Sectional drawing of three channels at different voltages

It can be seen that different wraps emerge at different voltages. The average forming depths of five channels are shown in Fig. 5. In Fig. 5, the forming depth increases with the increase of voltage, but the forming depth begins to decrease when the voltage reaches 9 000 V.

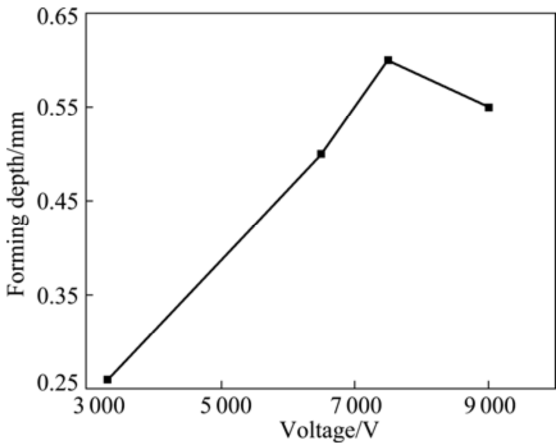

Fig. 5 Average forming depth of channel at different voltages

In Fig. 6, the die fitness of micro channel increases with the increase of the voltage. In Fig. 3 and Fig. 4, the deformation parts have different warps with the increase of the voltage. In Fig. 5, the channel depth reaches maximum at 7 500 V. Mathematical relation among the energy stored in the capacitor *W*, the charging voltage *V* and the capacitance *C* is shown in Eq. (1):

$$W = \frac{1}{2}CV^2 \tag{1}$$

The ability of deformation increases with the increase of voltage with fixed capacity. Some of the deformation power is absorbed by mold and die out as heat, and others consume as warp after touching the mold. So it leads to warp and decreasing in channel depth; Gas is enclosed in mold when parts touch the mold and can’t be exhausted because of high touching speed hampering die fitness. This is another reason of warps and decreasing in depth.

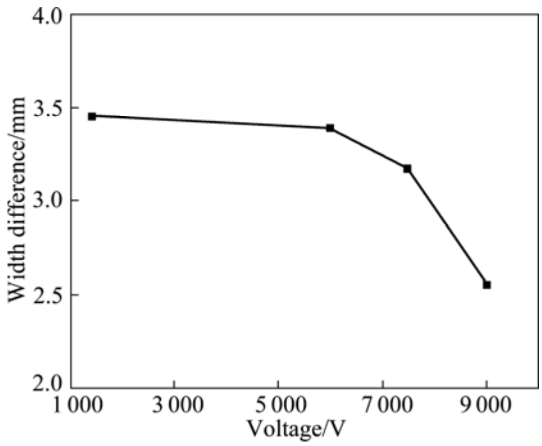

Fig. 6 Different channel width at different voltage

3.2 Effect of distances between die and sheet

The voltage was maintained at 10 500 V while the experiment spaces between sheet and die were 0.1, 0.3, 0.5, 1 and 2 mm, respectively.

Specimens were measured by laser scanning confocal microscope. Test curves of cross section and outline are shown in Fig. 7. The changes of curves in forming depth and width are shown in Fig. 8 and Fig. 9.

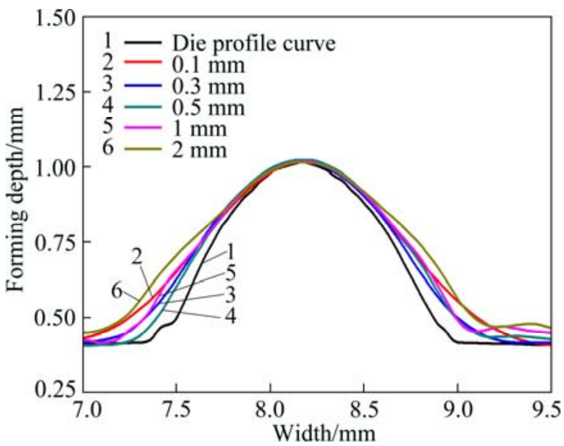

Fig. 7 Cross section of single channel under different distances

In Fig. 8, the forming depth of channels increases and the rebound phenomenon is weakened with the decrease of spaces. When the distance is 0.1 mm, and the forming depth of channel is 0.597 mm, little rebound phenomenon appears at the bottom of specimen.

In Fig. 9, the difference of forming width between forming and design size decreases firstly and then increases with distance shortened between parts and die. Channel width of deformation part is 1.82 mm when the distance is 0.5 mm. When the distance is 0.3 mm, the width of forming channel increases to 1.89 mm and the deformation sheet metal shows good quality. Fig. 10 shows photograph of parts.

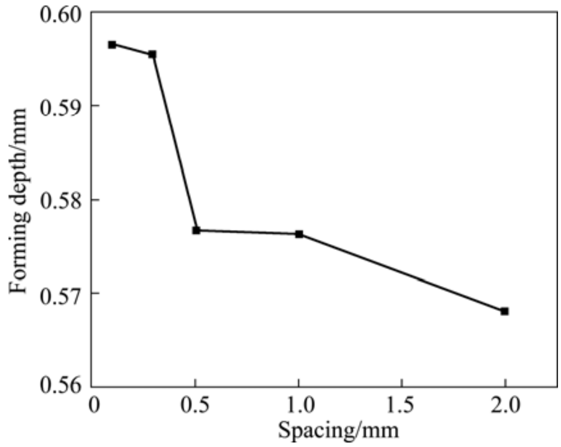

Fig. 8 Average forming depth of channel under different space conditions

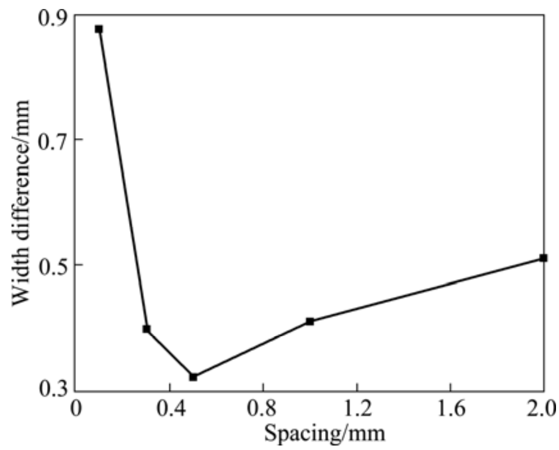

Fig. 9 Width differences under different space conditions

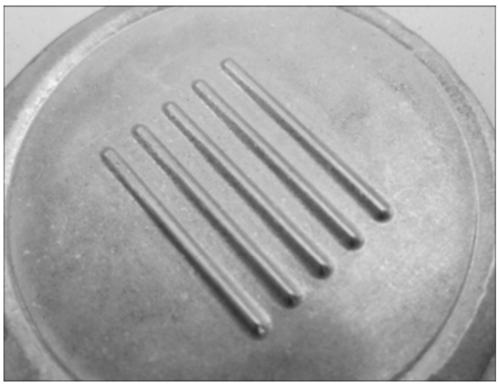

Fig. 10 Objective parts with distance of 0.3 mm at 10 500 V

In this test, the forming depth and width of channel increase with the increase of the mold depth, and reach the maximum at 0.5 mm of depth. It is due to high deformation speed and acceleration by electromagnetic force. Some of the power can be absorbed by mold and other dies as heat, the power remained consumed as rebound after toughing mold. When the mold depth increases, rebound and warp are weakened and the precision of forming size reaches the maximum, while reverse movement decreases. The mold depth decreases continuously, and the deformation characters and die fitness decrease, but the channel width increases and enclosed gas decreases.

4 Conclusions

1) Deformation depth and die fitness of micro channel increase with the increase of voltage with fixed mold depth, moreover, the forming depth reaches the maximum at 7 500 V. Revise movement leads to decreasing in channel depth and surface quality after the voltage reaches 7 500 V.

2) When the distance decreases, the forming depth increases, the rebound phenomenon is weakened, and channel depths reach the maximum. Quality of forming parts has been significantly improved.

3) Gas is enclosed in mold when the parts touch the mold and it can't be exhausted because of high touching speed hampering die fitness. This is another reason of warp and decreasing in depth.

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T2 铜薄板电磁微胀形成形

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摘 要：对 T2 紫铜薄板进行电磁微胀形有模成形实验，研究不同电压及不同凹模深度对材料成形性能的影响。采用激光共聚焦显微镜及轮廓仪研究不同充电电压和不同凹模深度下的制件截面轮廓、成形深度的变化规律。研究结果表明：凹模深度一定，随着电压升高微通道成形精度不断提高，成形深度在 7 500 V 出现极值，随后制件表面逐渐出现反弹迹象，成形深度降低，表面质量下降；而当电压一定，随着凹模深度的减小，成形深度随之增加，微通道成形精度逐渐提高，在凹模深度为 0.5 mm 时出现极值，随后精度逐渐降低，但随着凹模深度的降低制件表面的弹复现象逐渐减弱、排气不良留下的痕迹逐渐消失，表面质量不断提高。

关键词：薄板；微成形；微胀形；电磁成形

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