Trans. Nonferrous Met. Soc. China 19(2009) s790−s794

Transactions of Nonferrous Metals Society of China

www.tnmsc.cn

Effect of die cavity dimension on micro U deep drawing behaviour with T2 foil

WANG Chun-ju(王春举)[1], GUO Bin(郭 斌)[1, 2], SHAN De-bin(单德彬)[1, 2]

1. School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China;
2. Key Laboratory of Micro-systems and Micro-structures Manufacturing, Ministry of Education, Harbin Institute of Technology, Harbin 150001, China

Received 10 August 2009; accepted 15 September 2009

Abstract: The strips U deep drawing experiments were carried out to study the effect of die cavity dimension with an extension machine manufactured by SANS company. The effects of parameters were analyzed in deep drawing process under different experimental conditions, such as punch load, reduction of thickness, angle of U part and surface quality. The experiment results show that the punch load increases with the decrease of female radius, and larger blank holder force enlarges the range of increasing. With the increasing of blank holder force, the angle of U part increases, and the reduction of foil thickness at the corner becomes larger. Obvious scratch and accumulation at the die cavity corner were observed by SEM. The investigation results indicate that micro U deep drawing of foil is affected by micro die cavity dimension.

Key words: U deep drawing; die cavity dimension effect; springback; reduction of thickness

1 Introduction

It is foreseeable that micro electro-mechanical system (MEMS) as a technology of the integration of mechanics, electronics and software will take over more and more functions that were performed in the past purely by mechanical elements[1−3], which promotes rapidly the increasing demand of micro parts. Micro forming technology obtains wide attentions. When scaling down specimen dimension, the ratio of the mean grain size to the specimen dimension is changed, and the size effect occurs[4]. GAU et al[5] and MAHABUNPHACHAI and KOC[6] found that the yield strength and tensile strength decrease as *T*/*D* (thickness/ average grain size) ratio decreases until *T*/*D* approaches one. However, as the average grain size is greater than the thickness, the yield stress increases with large deviation as the *T*/*D* ratio decreases from the results of bending test. Several micro formings of thin sheet were investigated based on the researches of size effect. OCANA et al[7] studied the physics of laser shock micro forming and the influence of different effects on the net bending angle. VOLLERTSEN et al investigated the deep drawing of micro cup of 1 mm in diameter, and the limit drawing ratio was studied[4, 8−10]. WULFSBERG and TERZI[11] observed a dependence of the material micro structure. To minimize the effect of inhomogeneous material behaviour, micro forming at elevated temperature was performed by EICHENHUELLER, and the result showed a homogenizing effect which leads to a reduced process scattering[12]. For the existing of size effect, traditional FEM cannot be directly transferred to analyze the microforming process. JUSTINGER et al[13−15] considered the Taylor factors to estimate the conditions under which a micro forming process is likely to be influenced by single grain orientation and to explain the difference between flow stress determinations in micro tensile tests versus punch force in micro deep drawing. LI et al[16] studied the size effect in the micro-bending forming process of ultra-thin sheet based on the concept of strain-gradient plasticity. YEH et al[17] presented an effective and practical mathematical modeling to describe the material behavior of any thickness and any grain size in micro-forming, and the results of the FEM showed that thickness variety and stress distribution are reasonable.

During the miniaturization of cup deep drawing, size

Foundation item: Projects(50835002; 50805035) supported by the National Natural Science Foundation of China; Project(2008RFQXG041) supported by the Foundation for Innovation Scholars of Harbin, China

Corresponding author: WANG Chun-ju; E-mail: cjwang1978@hit.edu.cn

effects occur obviously. In this work, to simplify the stress state of foil in deep drawing and to study the effect of die cavity dimensions in details, a serial of U deep drawing experiments were carried out. The punch load, angle of U part, reduction of thickness, and surface quality were analyzed.

2 Experimental

The T2 copper foils of 0.05 mm and 0.09 mm in thickness were selected as experimental materials. They were machined to 10 mm×5 mm with electrical discharge machine (EDM). The chemical composition of the T2 foil is shown in Table 1. A strip U deep drawing die device was developed with two guide pillars to obtain high movement accuracy of punch. A punch holder and spring were accepted to get different blank holder forces by changing the length of spring as shown in Fig.1(a). The width of the female die, *W*, is 1 mm, and the radii of the female die cavity corner, *R*, are 0.1 mm and 0.3 mm, respectively. The clearance between male and female die is equal to the thickness of foil. The photograph of the die device is shown in Fig.1(b).

The tests were performed with an extension machine manufactured by the SANS company without lubrication at room temperature. There is a high accuracy load sensor in the extension machine, which is helpful to obtain high accuracy punch load. And the punch speed is selected as 10 mm/s.

Table 1 Chemical composition of T2 foil (mass fraction, %)

Cu	Sn	Pb	Zn	Others
≥99.9	≤0.002	≤0.005	≤0.005	Bal.

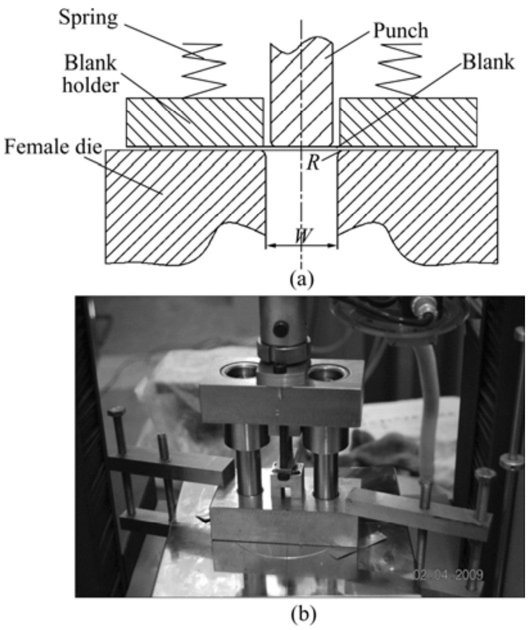

Fig.1 Schematic diagram (a) and photograph (b) of die device

3 Results and analysis

3.1 Effect of die cavity dimension on punch load

The micro U deep drawing experiments were carried out with the female die of 1 mm in width and 0.1 mm and 0.3 mm in radius, respectively. The thickness used in the tests is 0.05 mm. The effect of the die dimension is shown in Fig.2. The punch load increases with the decrease of female die radius. When a larger blank holder force is applied, the increasing range of punch load is enlarged. This result can be analyzed from the viewpoint of the bending deformation at the corner of female die. The reduction of radius at the female die corner leads to the decrease of the bending angle, which increases the plastic deformation of foil at the female die corner. And the punch load becomes larger.

With the increase of the blank holder force, the plastic deformation degree becomes larger for the increase of die fittingness. At the same time, the friction increases with the increase of blank holder force. Then, the increasing range of punch load becomes larger.

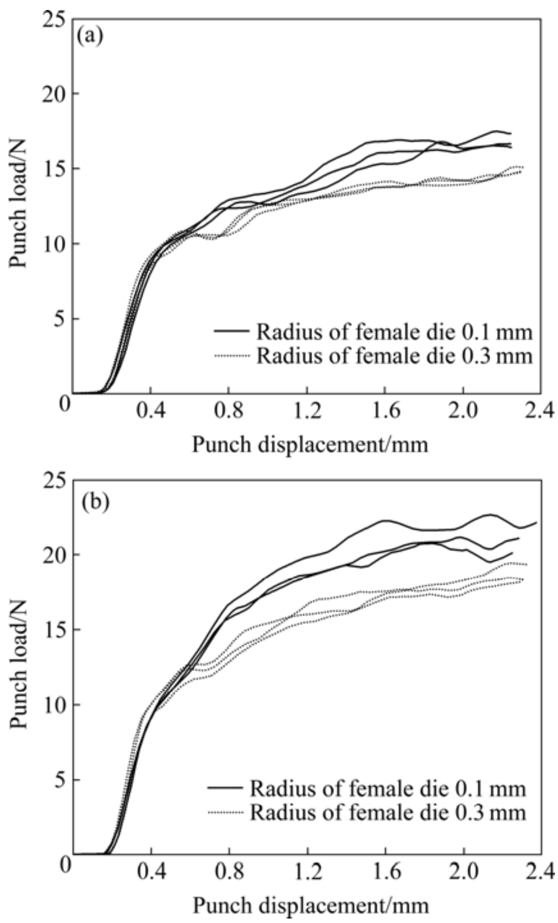

Fig.2 Curves of punch load vs displacement under different radius of female die: (a) Blank holder force 3 N; (b) Blank holder force 6 N

3.2 Effect of blank holder force on punch load

The effect of blank holder force was investigated with different radii of female die. The experimental results are shown in Fig.3. With the increase of blank holder force, the punch load increases. And the reduction of growth range is observed when a larger radius of female die is selected. We can analyze the results with the viewpoint of bending deformation. A larger blank holder force increases the die fittingness, which leads to the increase of punch load. When the radius of female die increases, it minishes the bending deformation degree at the corner. Then, the reduction of growth range appears.

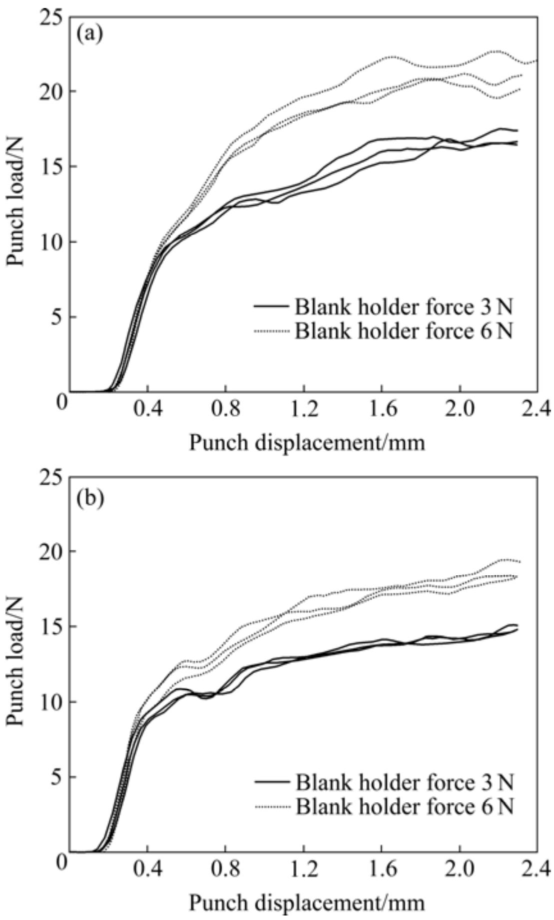

Fig.3 Curves of punch load vs displacement under different blank holder forces: (a) Radius of female die 0.1 mm; (b) Radius of female die 0.3 mm

To investigate the effect of foil thickness, the T2 foil of 0.09 mm in thickness was selected as the experiment material. And the width and radius of female die are 1 mm and 0.3 mm, respectively. The result is shown in Fig.4. The punch load increases with the increase of blank holder force. Comparison with Fig.3(b) shows that the increasing range is enlarged by the thickness of foil. The reason is that the increasing of blank holder force increases the die fittingness, which leads to the fact that the plastic deformation of thick foil is larger than that of thin foil. The difference of plastic deformation of two foils enlarges the increasing range of punch load.

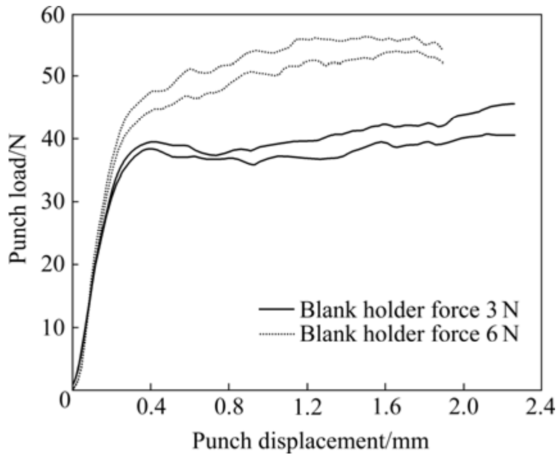

Fig.4 Curves of punch load vs displacement under different blank holder forces with T2 foil of 0.09 mm thickness

3.3 Analysis of micro U part quality

To evaluate the precision of micro part, the angle of U part was adopted as the evaluation parameter. The angle of U part was measured with a confocal scanning laser microscope (CSLM, OLS−3000, Olympus). Fig.5 shows the angle of micro U part formed with 0.09 mm-thick T2 foil under different blank holder forces. The results indicate that the angle of U part increases with the increase of blank holder force. This means that springback occurs obviously. The phenomena can be explained by the difference of plastic deformation between outer layer and inner layer of foil at the punch corner. At the outer layer, the tensile deformation occurs. However, the deformation is a compression deformation at the inner layer. The different kinds of deformation lead to the springback. Since the difference of deformation between outer layer and inner layer of foil is enlarged by the increase of blank holder force, the angle of U-part increases.

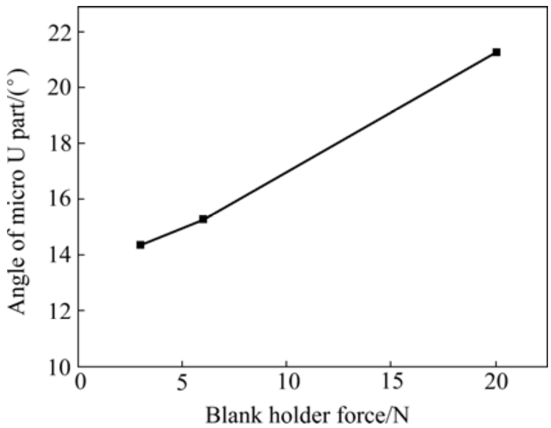

Fig.5 Angle of micro U part under different blank holder forces

The thickness of foil at the female die corner was measured by CSLM, and the results are shown in Fig.6. The reduction of thickness at the corner is observed clearly, and the reduction becomes larger with the increase of blank holder force. This means that the tensile deformation occurs at the side wall of U part, and the tensile deformation increases with the increase of blank holder force.

The surface of U part was analyzed by SEM, and the results are shown in Fig.7 and Fig.8. The scratch appears at the side wall of U part, and the accumulation of material occurs at the female die corner. With the increase of blank holder force, both scratch and accumulation become more severe. This is one of reasons for the reduction of thickness at the female die corner.

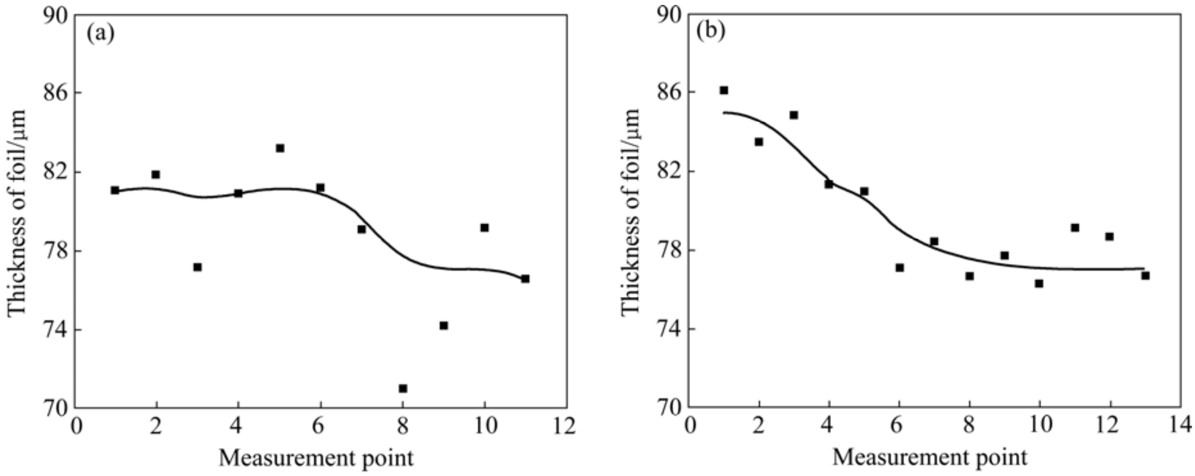

Fig.6 Reduction of thickness under different blank holder forces: (a) Blank holder force 3 N; (b) Blank holder force 20 N

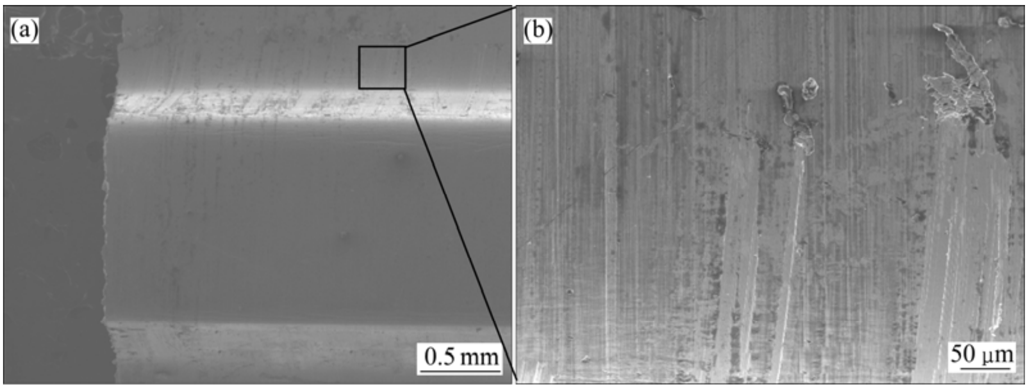

Fig.7 SEM images of micro U part (blank holder force 3 N): (a) Whole photograph; (b) Local photograph

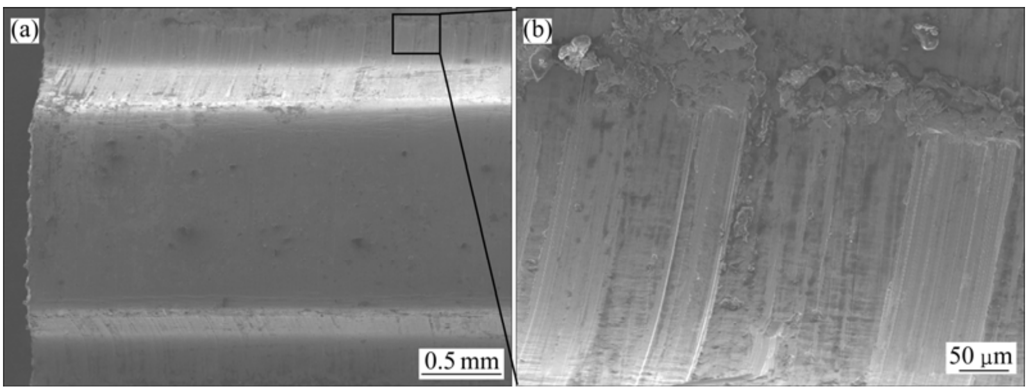

Fig.8 SEM images of micro U part (blank holder force 20 N): (a) Whole photograph; (b) Local photograph

4 Conclusions

1) The punch load increases with the decrease of female die radius. When a larger blank holder force is applied, the increase of punch load is enlarged.

2) With the increase of blank holder force, the punch load increases, and the increasing range is enlarged by the thickness of foil. A larger radius of female die leads to the reduction of growth range.

3) For the existing of springback, the angle of U-part increases with the increase of blank holder force. The reduction of thickness at the female die corner is observed clearly, and the reduction becomes larger with the increase of blank holder force.

4) The scratch appears at the side wall of U part, and accumulation of material occurs at the female die corner.

References

[1] GEIGER M, MERKLEIN M, TOLAZZI M. Metal forming ensures innovation and future in Europe [C]// BARIANI P F. Proceeding of the 8th ICTP. Verona, 2005.

[2] ENGEL U, ECKSTEIN R. Microforming—From basic research to its realization [J]. Journal of Materials Processing Technology, 2002, 125/126: 35−44.

[3] GEIGER M, KLEINER M, ECKSTEIN R, TIESLER N, ENGEL U. Microforming [J]. CIRP Annals-Manufacturing Technology, 2001, 50(2): 445−462.

[4] VOLLERTSEN F, SCHULZE NIEHOOF H, HU Z. State of the art in micro forming [J]. International Journal of Machine Tools and Manufacture, 2006, 46:1172−1179.

[5] GAU J T, PRINCIPE C, WANG J. An experimental study on size effects on flow stress and formability of aluminum and brass for microforming [J]. Journal of Materials Processing Technology, 2007, 184: 42−46.

[6] MAHABUNPHACHAI S, KOC M. Investigation of size effects on material behavior of thin sheet metals using hydraulic bulge testing at micro/meso-scales [J]. International Journal of Machine Tools and Manufacture, 2008, 48: 1014−1029.

[7] OCANA J L, MORALES M, GARCIA-BALLESTEROS J J, PORRO J A, GARCIA O, MOLPECERES C. Laser shock microforming of thin metal sheets [J]. Applied Surface Science, 2009, 255: 5633−5636.

[8] VOLLERTSEN F, HU Z, SCHULZE NIEHOOF H, THEILER C. State of the art in micro forming and investigations into micro deep drawing [J]. Journal of Materials Processing Technology, 2004, 151: 70−79.

[9] HU Z, VOLLERTSEN F. Friction test for deep drawing with respect to size-effects [C]// WANG Z R. Proceedings of the 1st ICNFT. Harbin, 2004: 153−158.

[10] SAOTOMEY, YASUDA K, KAGA H. Microdeep drawability of very thin sheet steels [J]. Journal of Materials Processing Technology, 2001, 113: 641−647.

[11] WULFSBERG J P, TERZI M. Investigation of laser heating in microforming applying sapphire tools [J]. CIRP Annals-Manufacturing Technology, 2007, 56(1): 321−326.

[12] EICHENHUELLER B, EGERER E, ENGEL U. Microforming at elevated temperature — Forming and material behaviour [J]. International Journal of Advanced Manufacture Technology, 2007, 33: 119−124.

[13] JUSTINGER H, HIRT G. Estimation of grain size and grain orientation influence (I): Microforming processes by Taylor factor considerations [J]. Journal of Materials Processing Technology, 2009, 209: 2111−2121.

[14] GEIGER M, GEISSDORFER S, ENGEL U. Mesoscope model—Advanced simulation of microforming processes [J]. Production Engineering, 2007, 1(1): 79−84.

[15] GEISSDORFER S, ENGEL U, GEIGER M. FE-simulation of microforming processes applying a mesoscopic model [J]. International Journal of Machine Tools and Manufacture, 2006, 46: 1222−1226.

[16] LI L, ZHOU Q, ZHOU Y Y, CAO J G. Numerical study on the size effect in the ultra-thin sheet's micro-bending forming process [J]. Materials Science and Engineering A, 2009, 499: 32−35.

[17] YEH F H, LI C L, LU Y H. Study of thickness and grain size effects on material behavior in micro-forming [J]. Journal of Materials Processing Technology, 2008, 201: 237−241.

(Edited by YUAN Sai-qian)