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Simulation of defects in micro-deep drawing of an aluminium alloy foil

Syamsul Hadi
University of Wollongong, sh879@uowmail.edu.au

Hai-liang Yu
University of Wollongong, hailiang@uow.edu.au

Kiet Tieu
University of Wollongong, ktieu@uow.edu.au

Cheng Lu
University of Wollongong, chenglu@uow.edu.au

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Abstract

Micro-forming refers to the application of conventional forming processes to manufacture products from ultra-thin sheet materials. While attempting to meet the increasing demand for cost-effective manufacturing of micro-formed components, it is very important to reduce the defects in the products. In this paper, we report a number of Finite Element (FE) simulations of the micro-deep drawing process with various sample thicknesses and eccentric distances. The simulations indicated that when the sample thickness is nearly equal to the gap between the plunger and the die, the sample is likely to develop fractures at the bottom corner. When the sample thickness is much smaller than the gap, wrinkling appears in the sample. If the sheet thickness is reduced, the wrinkles approach the bending zone. If the punch-die eccentricity is increased, the pressing process results in a defective product. The simulation results compared well with experimental results. This suggests that the computer simulations can be used to design future experiments.

Keywords

aluminium, drawing, deep, micro, foil, defects, alloy, simulation

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Simulation of Defects in Micro-Deep Drawing of an Aluminium Alloy Foil

Syamsul Hadi[a,c], Hai-liang YU[a,b,*], Kiet TIEU[a], Cheng LU[a]

[a] School of Mechanical, Materials & Mechatronic Engineering, University of Wollongong, NSW 2500, Australia
[b] School of Mechanical Engineering, Shenyang University, Shenyang 110044, China
[c] Mechanical Engineering Dept., State Polytechnic of Malang, P.O. Box 04 Malang 65100, East Java, Indonesia
Email: Hailiang@uow.edu.au

Abstract: Micro-forming refers to the application of conventional forming processes to manufacture products from ultra-thin sheet materials. While attempting to meet the increasing demand for cost-effective manufacturing of micro-formed components, it is very important to reduce the defects in the products. In this paper, we report a number of Finite Element (FE) simulations of the micro-deep drawing process with various sample thicknesses and eccentric distances. The simulations indicated that when the sample thickness is nearly equal to the gap between the plunger and the die, the sample is likely to develop fractures at the bottom corner. When the sample thickness is much smaller than the gap, wrinkling appears in the sample. If the sheet thickness is reduced, the wrinkles approach the bending zone. If the punch-die eccentricity is increased, the pressing process results in a defective product. The simulation results compared well with experimental results. This suggests that the computer simulations can be used to design future experiments.

Keywords: Micro-forming, Al Sheet, Wrinkling, Fracture, Finite Element Simulation

INTRODUCTION

Micro-forming is an emerging manufacturing process that involves the fabrication of products from ultra-thin sheet material. The thickness of the sheet material may range from 0.001 mm to 0.3 mm. There is a great demand for micro-formed products. The development of adequate manufacturing facilities that can supply micro-formed parts in large numbers is therefore a key factor in the successful development of this process [1].

One of the main challenges in this technology is to transfer processes tested on a laboratory scale to actual industrial production lines, while avoiding wastage of material. To achieve this, numerical simulation of the micro-forming process offers an attractive alternative to actual physical experiments that are often too expensive to perform repeatedly. The numerical simulations can be used to determine the optimum process parameters and the most favorable working conditions. Finite Element (FE) modelling is a powerful tool that can be used to predict the outcome of a micro-forming process carried out under different conditions, such as different blank holder techniques [3]. Simulation of the micro-forming process using Abaqus Dynamic explicit code and the static ITAS3D code was carried out by Kawka et al [4].The simulations produced different results in terms of number, distribution and shape of wrinkles. Wang et al [5] showed that the punch load increased with decreasing die radius. If a larger blank holder force was applied, there was a corresponding increase in the required punch load. A larger die radius was seen to result in reduction of the growth range. Chang et al [6] showed that the LDR can reach 2.0 at a forming temperature of 150°C and drawing velocity of 15 mm/s. Their simulation showed that use of the Variable Blank Holder Force technology could improve the LDR from 3 to 3.5, and could reduce the wall thinning ratio from 15.21% to 12.35%. Venkateswarlu et al [7] studied the micro-forming of circular cups using two different Al alloys. Their simulations using Deform-2D demonstrated that a greater cup depth was possible at elevated temperatures. The forming limit and necking location were successfully predicted, and occurred at the same the optimum temperature of both blanks. The FEM software Deform-3D was used to simulate elliptic cup deep drawing of a Magnesium alloy sheet at elevated temperature by Yang [8]. This study also investigated the effective stress and forming load under different process conditions, including die profile radius, the clearance between punch and die cavity, blank holder force and temperature. Chan et al [9] showed that the experimentally observed material flow behavior during double cup extrusion was very similar to their simulation results. Ehlers [10] found that due to stress localization in the necking region, the effective stress deviated significantly from the longitudinal stress, so that determination of true stress was problematic. With increasing element lengths plate responses slightly stiffer prior to the fracture. With decreasing element lengths resulting force-displacement curve met test curve.

The defects that can occur during drawing are wrinkling, tearing, earring and scratching. Wrinkling can occur in the flange or in the wall. Wrinkling in the flange occurs due to compressive buckling in the circumferential direction, and can be prevented by a sufficiently high blank holding force . Wrinkling in the wall occurs when a wrinkled flange is drawn into the cup. If the clearance is too large, it results in a large

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unsupported region. Tearing occurs because of high tensile stresses that cause thinning and failure of the metal in the cup wall. A sharp corner radius can also cause tearing during the drawing process. Earring occurs when the material is anisotropic with properties in different directions. Scratches on the cup surface can be seen on the drawn part if the punch and/or the die are not smooth or inadequately lubricated in the process. Experiments on deep drawing by Yagami et al [11] for a Cu alloy showed that wrinkles could be successfully eliminated if the initial wrinkle depth was limited to 200 μm or less. Their FE simulations indicated that deep-drawability can be improved by restricting ductile damage by blank holder control. The deep drawing of a square mild steel cup was simulated using Abaqus-Vmat, using 3D brick elements by Fan et al [12]. Their results indicated that by increasing blank holder force, the degree of wrinkling can be reduced, and wrinkles disappear completely when the blank holder force is ~10 kN. Marumo et al. [13] found that the blank holder force required for the elimination of wrinkling increased rapidly as the thickness decreased, and was strongly influenced by the friction coefficient value.

In this paper, we used FEM modeling to analyse the evolution of defects in blanks, using different blank thicknesses and eccentric displacements during micro forming. It was found that cracking may occur when the blank thickness is greater than a threshold value. When the blank thickness is less than the threshold value, wrinkling occurs in the workpiece. It was also found that decreasing the blank thickness results in a larger wrinkling zone.

MODELING AND SIMULATION

FIGURE 1a shows a schematic diagram of the deep drawing process. The geometrical dimensions are listed in **TABLE (1)**.

TABLE (1). Geometrical Parameters in Deep Drawing in **FIGURE. 1a**

Parameters	Value
Diameter of blank (D_B), mm	14
Thickness of blank (T_B), mm	0.10 ~ 0.29
Diameter of drawing die (D_D), mm	8.25
Radius at corner of die (R_D), mm	1.21
Diameter of punch (D_P), mm	7.49
Radius at corner of punch (R_P), mm	1.21
Eccentricity ratio (E_D/D_B) %	0% ~ 15%

In the models, the punch, die, and blank holder are assumed as rigid, and the blank material is an AA1235 foil. The main material parameters for the blank are listed in **TABLE (2)**.

TABLE (2). Main Material Parameters

Parameters	Value
Density of blank, kg/m^3	2700
Young’s modulus of blank, GPa	80
Yield stress of blank, MPa	100
Poisson’s ratio of blank	0.3

A three-dimensional geometrical model of the micro-deep drawing of a aluminum foil was established with the parameters above. The blank was meshed with quadrilateral shell-shape elements by using LS-DYNA. **FIGURE 1b** shows the geometry model. In the models, there are 47788 elements and 54009 nodes, where 30000 elements and 30201 nodes for the blank. In the simulated deep drawing process, the punch presses at a constant speed. The Coulomb friction model is employed with the friction coefficient set at 0.1.

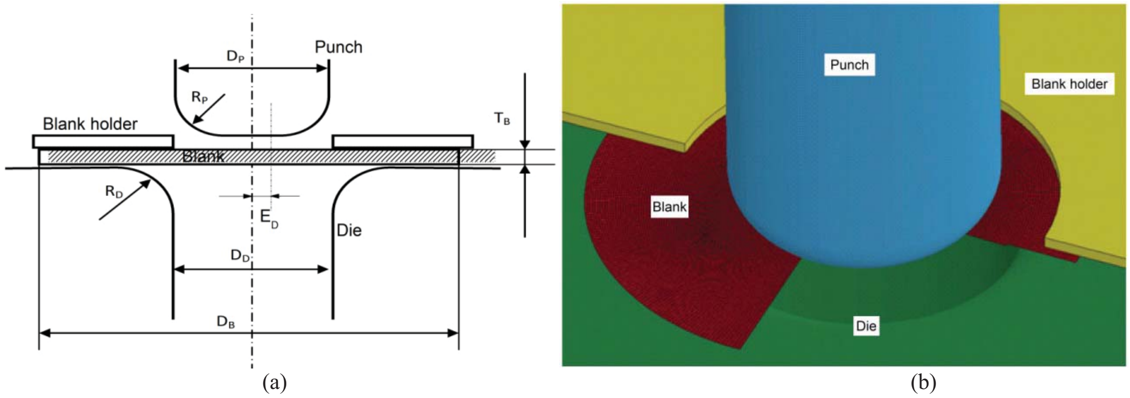

FIGURE 1. Geometric Dimensions and FE Model

RESULTS AND DISCUSSIONS

FIGURE 2 shows the simulated shapes of the drawn cups under different initial blank thicknesses. When the blank thickness is 0.29, it might cause the crack at the bottom corner between cup wall and the bottom side, as shown in **FIGURE 2a**. The simulations indicate that when the blank thickness is in range 0.25 ~ 0. 27 mm, a good quality product results. However, when the blank thickness reduces to 0.2 mm, wrinkling occurs on the wall. The thinner the initial blank, the deeper is the wrinkling on the cup wall.

FIFURE. 3 shows the corresponding experimental results for different blank thicknesses. When the blank thickness is 0.28 mm, there are no wrinkles seen. Wrinkling on the wall is seen on samples with blank thicknesses 0.13 mm and 0.07 mm.

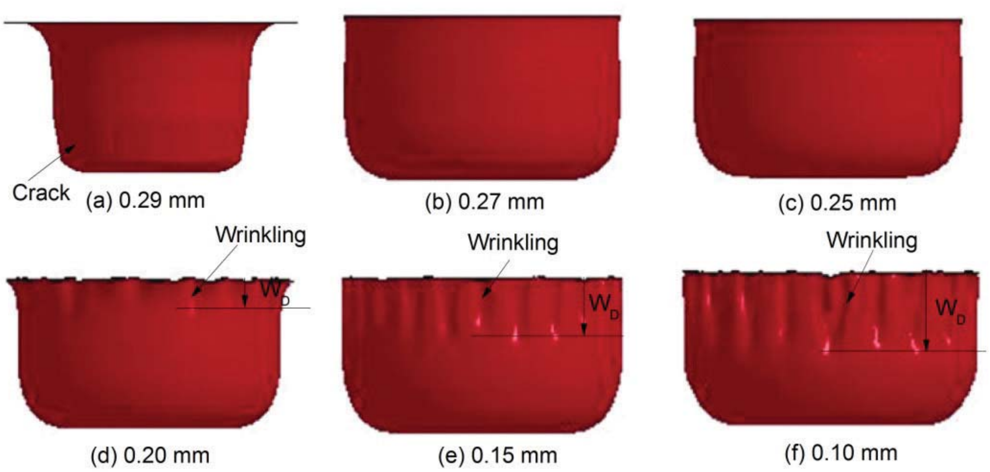

FIGURE 2. Simulation Results with Different Initial Blank Thicknesses

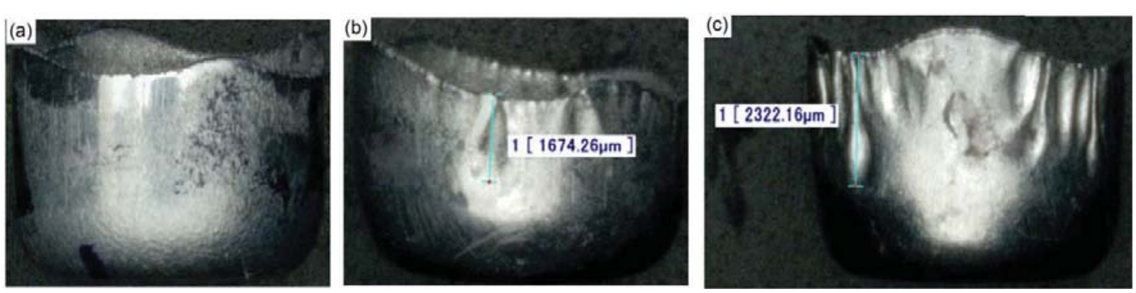

FIGURE 3. Experimental Samples with Blank Thickness (a) 0.28, (b)0.13, and (c) 0.07 mm

FIGURE 4 shows the ratio of wrinkle depth to cup depth as a function of blank thickness. When the blank thickness is 0.1 mm, the ratio is 55%. Overall, the simulation results are in good agreement with experimental results, especially in the range 0.1 mm to 0.2 mm.

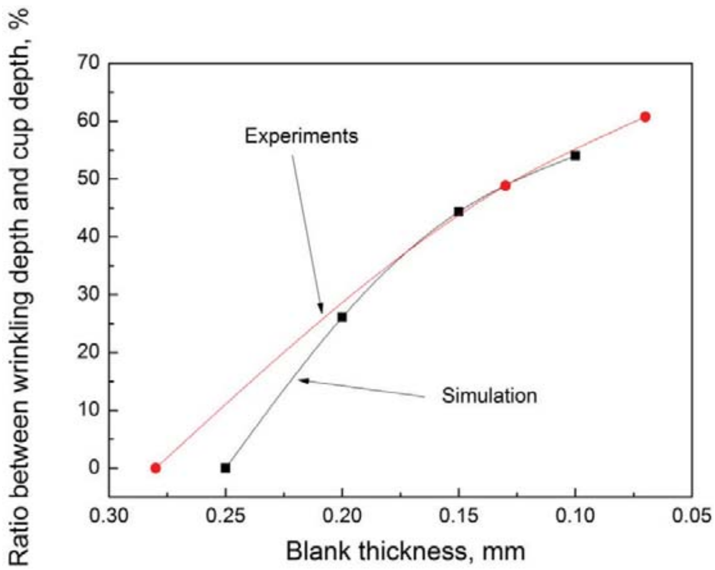

FIGURE 4. Wrinkling Depth under a Variety of Blank Thicknesses

From the corresponding punch force vs stroke (represented by press depth) curves, we see that that the thinner the initial blank, the smaller the required punch force, as shown in **FIGURE 5**. When the blank thickness is 0.29 mm, cracks may appear at the bottom corner. We could found that there is a shape down of the punch force. In addition, the wave zone of punch force in the process begins gradually forwards. For initial blank thicknesses of 0.1 mm and 0.15 mm, the curves in **FIGURE 5** are wavy, indicating the formation of wrinkles.

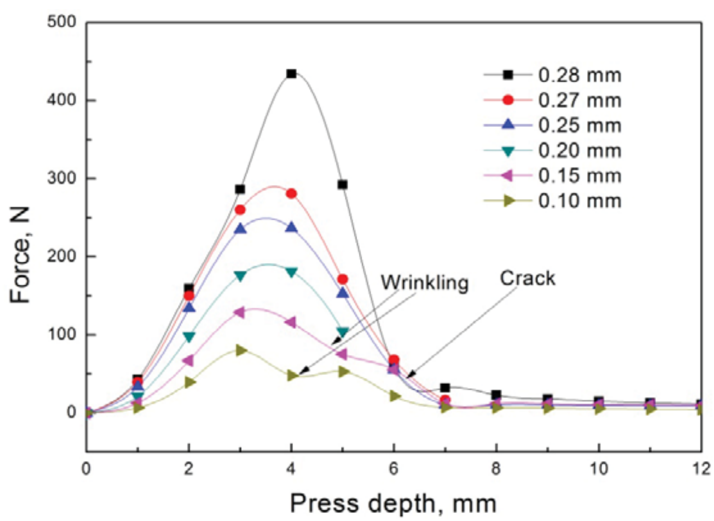

FIGURE 5. Punch Force during Deep Drawing under Different Blank Thicknesses

Setting the blank eccentrically over the die results in the formation of asymmetric cups. **FIGURE. 6** presents the influence of eccentricity on the workpiece shape. The simulations were carried out for blank thicknesses of 0.25 mm and 0.20 mm, with eccentricities of 5%, 10% and 15%, as defined in Figure 1 and Table 1. Higher eccentricity results in greater distortion. When the eccentricity is less than 5%, the cup shape can be acceptable. However, when the eccentricity is greater than 10%, the blank cannot be drawn into a cup with an acceptable shape. Fig. 7 shows the experimental results for eccentricities of 10% and 20%. Compared with the simulation results, they are in good agreement.

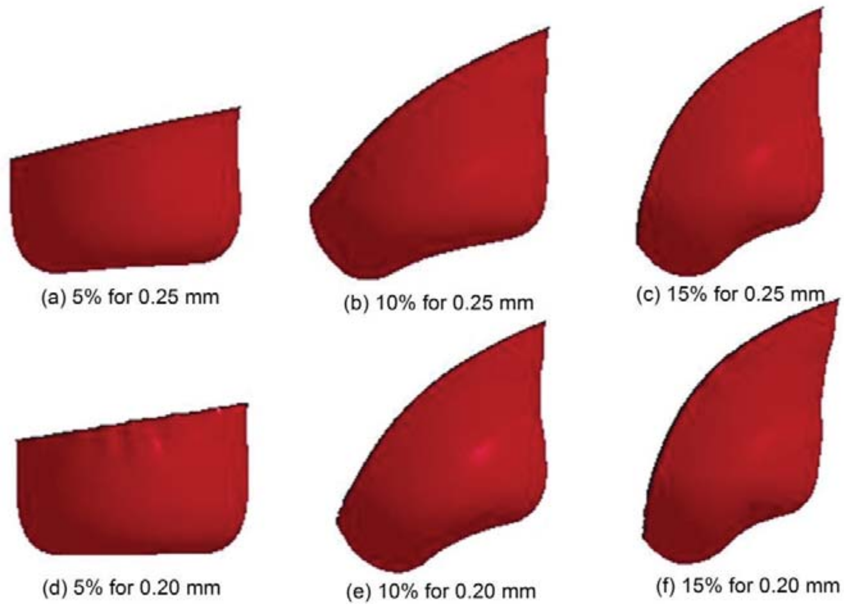

FIGURE 6. Simulation Results with Different Eccentric Distances

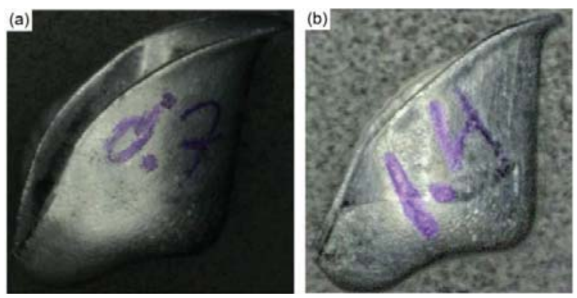

FIGURE 7. Experimental Samples with Eccentric 10% and 20% for Blank Thickness 0.28 mm

FIGURE 8 shows the punch force vs stroke curves for various eccentricities. The higher the eccentricity, the smaller is the punch force. When the eccentric distance reaches 15%, there is a great platform for punch force.

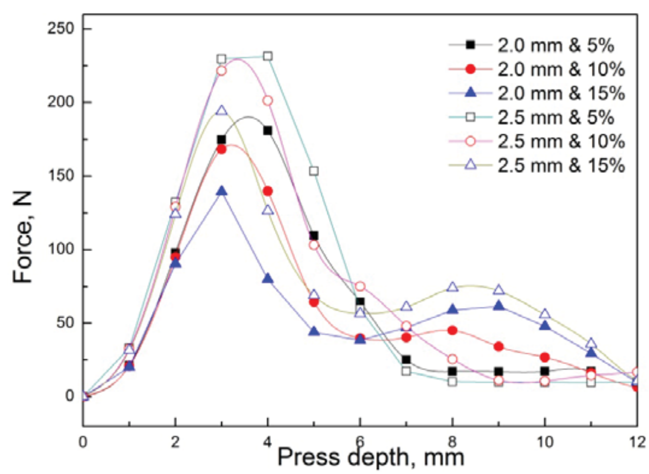

FIGURE 8. Punch Force during Deep Drawing under Different Eccentric Distances

Comparing the defects in **FIGURE 2** and **FIGURE. 6** and the change of punch force in **FIGURE 5** and **FIGURE 8**, it is seen that we can predict the quality of product for given process parameters.

CONCLUSIONS

(1) Good quality of micro-deep drawing products could be obtained in a certain range of initial blank thickness. For initial blanks thicker than the upper limit of this range, cracks may occur at the bottom corner of the drawn cups, while when the blank thickness is lower than the range, wrinkling is likely to occur on the flange.

(2) When the eccentricity is less than 5%, the product may still be acceptable. When the eccentricity is larger than ~10%, the product quality is unacceptable.

(3) The defects that may occur during micro-deep drawing can be predicted by the numerical simulations.

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REFERENCES

1. Y. Qin, Y. Ma, C. Harrison, *et al*. Int. J. Mater. Form. **1**, pp475-478(2008).
2. S. Geiβdörfer, U. Engel and M. Geiger. Int. J. Mach. Tool. Manuf. **46**, pp1222-1226 (2006).
3. A. Wifi and A. Mosallam. J. Achieve. Mater. Manuf. Eng. **24**, pp315-323 (2007).
4. M. Kawka, L. Olejnik, A. Rosochowski, et al. J. Mater. Process. Technol. **109**, pp283-289(2001).
5. C. Wang, B. Guo and D. Shan. Trans. Nonfer. Metal. Soc. China. **19**, pp790-794(2009).
6. Q. Chang, D. Li, Y. Pen, et al. Int. J. Mach. Tool. Manuf**.47**, pp436-443(2007).
7. G. Venkateswarlu, M. J. Davidson and G. R. N. Tagore, ARPN J. Eng. Appl. Sci. **5**, pp93-98(2010)
8. T.S. Yang, J. Achieve. Mater. Manuf. Eng. **27**, pp139-142 (2008).
9. W.L. Chan, M.W. Fu, and J. Lu. Mater. Des. **32**, pp525-534(2011)
10. S. Ehlers. Thin-Walled Struct. **48**, pp1-8(2010).
11. T. Yagami, K. Manabe and Y. Yamauchi. J. Mater. Process. Technol. pp187-188, 187-191(2007).
12. J.P. Fan, C.Y. Tang, C.P. Tsui, et al. Int. J. Mach. Tool. Manuf. **46**,pp1035-1044 (2006).
13. Y. Marumo, H. Saiki and L Ruan. J. Achieve. Mater. Manuf. Eng. **20**, pp479-482 (2007).