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EXPERIMENTAL EVALUATION OF SIZE EFFECTS IN MICRO DEEP DRAWING PROCESS OF THIN FOIL MATERIALS

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Abstract: Micro deep drawing of metallic cups is a cost effective technique if the parameters are suitably identified, but reducing dimensions increases the difficulties in manufacturing. In this work, formability study of pure copper foils and thickness distribution in micro deep drawing are carried out. The pure copper C1100 foil thickness of 100, 200 and 300 µm is selected and the limit drawing ratio is determined. In order to determine the forming depth in micro scale and force required in formed parts, a micro deep drawing tool assembly is developed. The results shows that 300 µm foil exhibits good formability in tensile test and Ericson cupping test. The excessive reduction in thickness specifically at the cup shoulder corner and the upper part of the side wall is located. The thinning is identified maximum at the side wall of the cup along the transverse direction. The results indicate that copper micro cups with high quality can be efficiently produced with appropriate forming parameters.

Keywords: Micro forming; cupping test; copper foils; formability; thickness distribution

INTRODUCTION

Microforming is an appropriate technology to manufacture very small metal parts, in particular for bulk production. Micro deep drawing process, which is a basic process of microforming to forming hollow, thin walled micro parts, is being one of the research focuses in microforming [1]. This process is prompted by the rapid development of micro electro mechanical systems, electronic industries and new energy and biomedical in recent years because of its high efficiency, high precision, mass production and low cost [2]. But better understanding of the process in relation to miniaturization is required to improve process stability, because several aspects of the process change when scaled down.

As a basic process of manufacturing, deep drawing provides a great application potential. But smaller the dimensions of part, the more difficult in manufacturing because of size effects. These size effects affect the tribology, which plays a great role in many forming technologies. This process involves forming products from metal foil of thickness ranging from 30 µm to 300 µm. In this work, a deep drawing process is carried out to produce micro cups using thin copper foils with a microforming die. The formability characteristics are studied for thin copper foils by using tensile tests and Erichsen cupping test. The forming force and thickness distribution is identified using microforming setup consists of a punch and die.

LITERATURE REVIEW

Micro deep drawing provides a great application potential to generate the mass production of micro-metallic cups of significantly lower overall cost and high quality [3]. Investigations in micro deep drawing are carried out and the limit drawing ratio was determined and the influences of friction coefficient at the flange and at the die radius are analyzed by vollersten et al. [4]. M.W. Fu et al. [5] conducted experiment of micro blanking and deep drawing using pure copper sheets with different grain sizes. The thinnest region appears at the bottom radius, while the bottom center region remains almost unchanged. Uneven thickness distribution along the cup axis is predicted in the surface and micro structural models are developed as a result of micro-friction and material heterogeneity [6]. Micro parts with two layers, copper and composite material annealed at 400 ºC is formed with micro deep drawing process. The formed cup shows no fracture and fewer wrinkles is reported by Fanghui et al. [7].

The pure copper C1100 conical cylindrical cups are successfully formed and thickness distribution is shown by Feng et al. [8]. Ihsan Irthiea et al. [9] recommended for the thin sheets to adopt relatively big initial gaps but not more than a particular limit. It may lead to excessive wrinkles at the shoulder corner and the flange region. It is proved that the stainless steel 304 cups with large aspect ratio can be produced by the micro deep drawing process by using flexible die. Polyethylene film is employed as lubricant in deep drawing of micro cups. The lubricant shows the significant decrease in forming load [10]. Liang Luo et al given that grain size affects micro deep drawing process and cup quality [11].

Chun-juwang noticed that there are many debris of copper sheet left on the contact surface of blank holder and female die after micro-deep drawing [12]. It is concluded from literature review that no sufficient research on parameter assessment for micro deep drawing operation. In this work, experimental investigations into micro deep drawing are carried out and the limit drawing ratio is determined.

EXPERIMENTS

To investigate the formability of material and thickness distribution, a robust die assembly is designed and micro deep drawing of pure copper C1100 of 100, 200 and 300 µm thickness have been conducted. The tensile test, Ericson cupping test performed in this work and die assembly are discussed in the subsequent sections.

— Tensile test

The tensile tests have been carried out to examine the mechanical properties on micro tensile testing machine. The specimens used are shown in Figure 1.

Figure 1. Micro tensile test – copper C1100 foil

The sheets are cut into dog-bone shape for tensile test according to the ASTM standard specifications E8-04 [13].

— Erichsen cupping test

In Erichsen test, the punch is pressed into the sheet until fracture occurs. The depth of the bulge is noted at the fracture point. It is used to evaluate the formability of sheet metal based on the alloy and sheet thickness. In this experiment, nine samples (Figure 2.) of three different thickness of copper foil are taken and their responses are summarized in Table 1.

Table 1. Observations made during Erichsen cupping test of copper foil.

Thickness	Comments
100 μm	Uneven distribution of load and material tries to wrinkle while cupping
200 μm	Poor depth of deformation
300 μm	High depth of deformation and uniform thickness distribution

Figure 2. Erichsen cupping test – copper foil

— Experimental setup

Experimental set up developed to conduct micro deep drawing experiments, consists of three primary parts namely movable punch, blank holder and clamping plate. The copper C1100 circular blanks are made from 300 μm thickness by using the blanking punch and die sets shown in Figure 3.

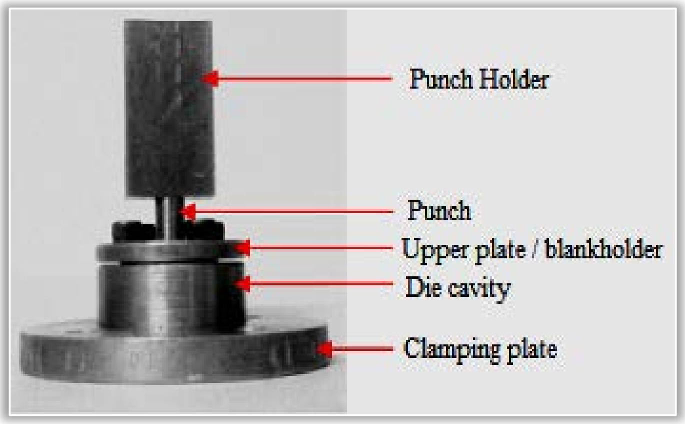

Figure 3. Micro deep drawing -Die assembly

The dimensions of the primary components in the die assembly are given in Table 2. In order to achieve the good shearing quality, clearance between the punch and die is to be 12-24 % of the initial foil thickness and it should be adopted for the punch-die set. The blanking tool setup is designed with about 45 μm clearance on its circumference.

Table 2. Geometrical parameters of micro-deep drawing die

Blank holder plate (mm)	Ø 50
Bottom plate (mm)	Ø 100
Punch (mm)	Ø 10

The experiments are conducted in zwick 10 kN capacity machine with punch velocity of 0.1 mm/s, punch load of 2373 N and blank holding force of 9.741 N. Figure.4. Shows the micro cups successfully produced under these forming conditions. In fact, the aspect ratios of the parts at different thickness are slightly various depending on how the sheet material sufficiently produces cups without any undesired tears.

Accordingly, results obtained that the final depths of the cups produced with different thick foils of 200 μm and 300 μm are 4.8 mm and 6.5 mm respectively. If it is formed beyond this limit, there will be the initiation of crack occurs at the interaction between wall and bottom of the cup near the shoulder (Figure 5) and it is propagated to the wall of the cup.

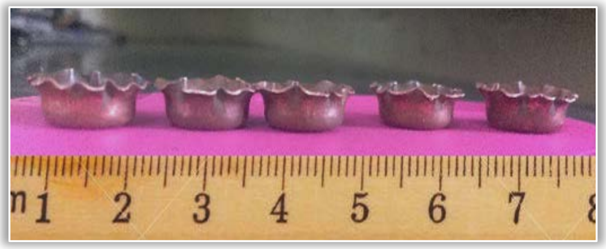

Figure 4. Cups formed with different initial thickness

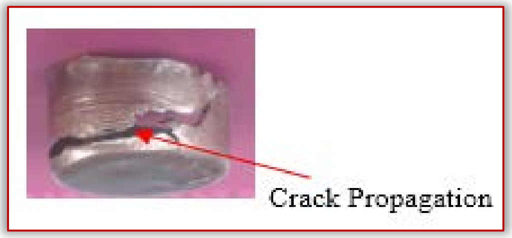

Figure 5. Failure by crack propagation

RESULT AND DISCUSSIONS

The influence of the copper foil thickness, depth of formation, thickness distribution, failure mode, crack propagation and quality of the formed cups are investigated through these experiments. The results show that depth of deformation is 9, 5 and 4 mm for 300, 200 and 100 μm foil. It exhibits that the 300 μm has good formability in tensile test and Ericson cupping test.

— Deep drawing force

The deep drawing force with deep drawing punch stroke for 300 μm thick copper foil is plotted. The peak indicates the maximum force required for deep drawing process and the slope after 4 mm depth shows possibility of crack propagation. The five trials have been conducted at room temperature of 29 °C with no lubrication condition. The various regions of deformations are shown in Figure 6 and the maximum failure load is 2400 N.

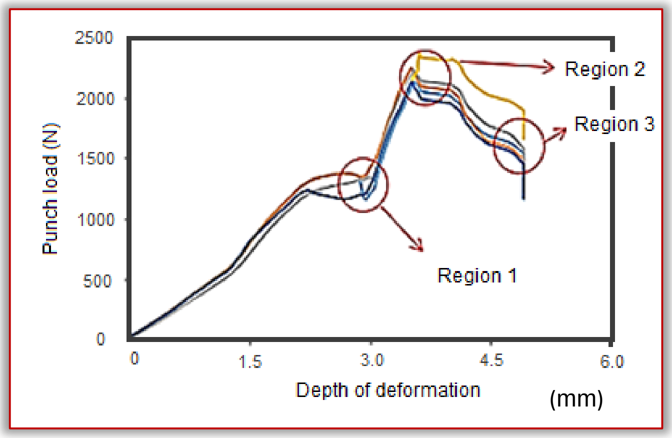

Figure. 6. Depth of deformation Vs Punch load on five trials

In region 1 is at which the depth of deformation crossed 3 mm material. In region 2, the blank is subjected to maximum force before attaining a cup height of 4 mm. During region 3, failure happened when depth of deformation approached around 4.8 mm. Hence it is clearly observed that drawing force decreases with the increase of grain size for each thickness size except the fracture case occurred in 300 μm, while under the particular grain size the load increases with the increase of thickness.

— Thickness distribution

The thickness of the deep drawn cup is measured and the thickness distribution is obtained for the side wall and bottom of the cup.

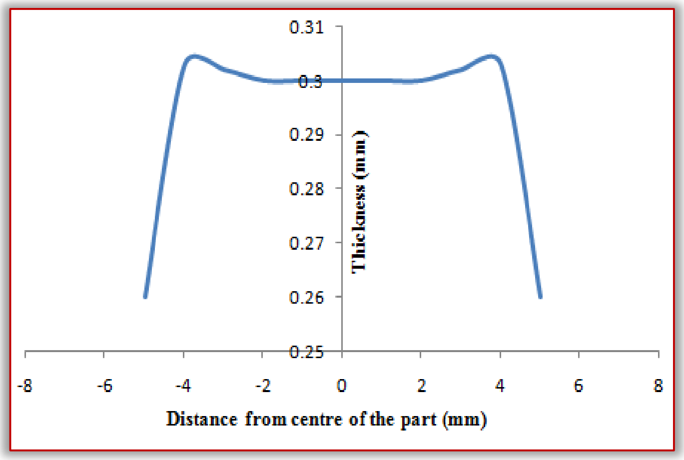

Figure. 7. Thickness distribution along circumference of cup

The thickness measurements are carried out at various points along the curvilinear path of the sectioned cup. The curves (Figure 7) relating to the thickness distributions along the transverse direction declare that the maximum thinning are observed in the side wall region of the cups and bottom of the cup shows no thickness variation.

CONCLUSIONS

Fundamental understanding of micro deep drawing technique is established by this work. Additionally, it has been found that the scaling effects not only appear within the process but also must be taken into account in all other areas of the forming process. Based on the micro drawing experiments with different thickness copper foils, the following conclusions are made:

- It is found that 300 μm thick foils are very much suitable for Micro cylindrical cups forming.
- The formability of 300 μm thick foils is found better than the 100 μm and 200 μm thick.
- Excessive reductions in thickness are found at the cup shoulder corner and the upper part of the side wall.
- Initial crack starts at the bottom corner radius of the cup and it propagates to the wall of the cup.
- It is identified that the thinning is maximum at the side wall of the cup along the transverse direction.

FUTURE WORK

Incorporating the micro deep drawing technique proposed in this work on a most widely used industry need materials such as brass, aluminium, and even plastic materials for miniature parts. It is possible to study the effect of friction in micro deep drawing process and its reduction by using nano lubricants can be studied.

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