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Research on Deep Drawing Technology for Tiny Parts Applied in the Electrical-Electronic Industry

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Abstract— **Meso-and microforming is a technology to shape parts from extremely small metal billets. Parts with geometric dimensions are a few millimetres to a few micrometres. With the rapid development of the electrical-electronics industry and biomedical engineering, the technology of forming microscopic parts has been researched and applied because of its efficiency, accuracy, and high productivity. Deep drawing is an operation that turns flat sheet metal blanks into hollow, open-mouth parts. It is an essential process in sheet metal stamping. Micro deep drawing is one of the micro-shaping technologies that has been widely studied and applied in recent years. However, the bases for calculating technological and geometrical parameters in the micro-deep drawing have not yet been analyzed and evaluated in detail. Therefore, this paper has proposed a theoretical basis combined with simulation applied to the design of technology to manufacture a connector head part drawing die with a diameter of 300µm and height of 1500µm using materials SUS304 material. Numerical simulation also allows evaluation of the stamping part's internal stress state, the ability to pull the workpiece into the die, and the thickness distribution on the product wall. Experimental research has also verified that, with the determined parameters, the stamping parts meet the quality requirements. This indicates the proposed calculation methods for the tiny deep drawing operation are entirely suitable. The results of this research can be wholly applied to the production of micro-sized cylindrical cup parts using the deep drawing method.**

Keywords—**Micro-Meso forming; deep drawing; metal forming; electronic components.**

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I. INTRODUCTION

The demand for producing microscopic parts used in many industries, including electricity-electronics, computers, and biomedicine, is increasing [1]. Micro-part forming technology has strong applicability because of its attractive characteristics: high productivity, good quality, and low cost [2], [3], [4]. Stamping of microscopic parts is one of the microforming technologies to form hollow metal parts. Microforming is one of the micro-manufacturing processes, which provides a promising way to fabricate metal parts, such as connector pins, miniature screws, micro gears, micro shafts, chip lead frames, and IC sockets. Because of the widespread applications of deep drawing, research on this stamping method has attracted researchers' attention, and many works have been published in recent years. Research on the influence of punch speed on product quality was reported in 2021 by Ken-ichi Manabe [5]. Research projects on the influence of parameters such as blocking force and die geometry on the quality of stamping products, such as limiting earing height, wrinkling, and tearing [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. Research on the effects of friction to improve drawing efficiency has been published [17], [18], [19], [20], [21], [22], [23], [24], [25]. The influence of material parameters on the quality of stamping products has been reported [26]. However, the above works are only applied to macroforming products, and research on micro-stamping methods is still relatively limited. In 2021, Liang Luo and co-workers reported the effect of blocking force in microclaw stamping [27]. Reports on the impact of grain ratio in micro-forming have been published [28], [29], [30]. Jingwei Zhao and his colleagues experimentally studied the micro-deep drawing of stainless steel sheets with different microstructural characteristics [31]. The above research works have not explicitly mentioned the method of calculating and designing stamping molds for microscopic parts. Therefore, research to propose methods for calculating, evaluating, and determining parameters of workpieces and shaping tools is very important and will serve as the foundation for further research. The subject of this research is micro-deep drawing technology to manufacture contact head-shaped details for application in the electrical and electronics industry.

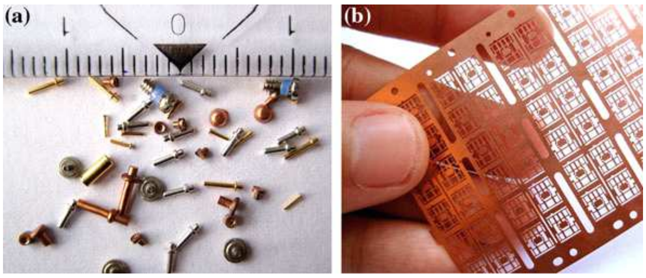
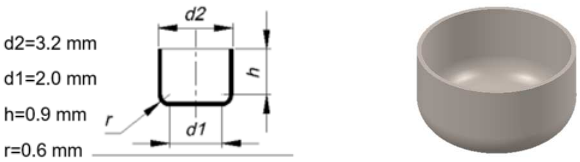


Fig. 1 Micro parts used in industry [4]: a)Massive forming of microscopic parts b) Stamping tiny parts from sheet metal billet.

II. Materials and Method

A. Research Objects and Methods

The research part is shaped like a cylindrical cup, a component used as a contact tip in electrical and electronic products. Geometric parameters of forming part: cylindrical cup-shaped connector head part, diameter of 3000 μm, height of 1500 μm (Fig. 2)



a) b)

Fig. 2 Detailed geometrical parameters of the connector head: a) 2D product dimensions b) 3D product model

The material used in this study is SUS304 stainless steel with a thickness of 100 μm with the composition of chemical elements by mass shown in Table 1 and Figure 3.

TABLE I
CHEMICAL ELEMENTAL COMPOSITION OF SUS304 BY MASS (%)

No	Element	Content	Unit
1	Cr	18	%
2	Ni	8.1	%
3	Mn	First	%
4	Fe	Remaining	%

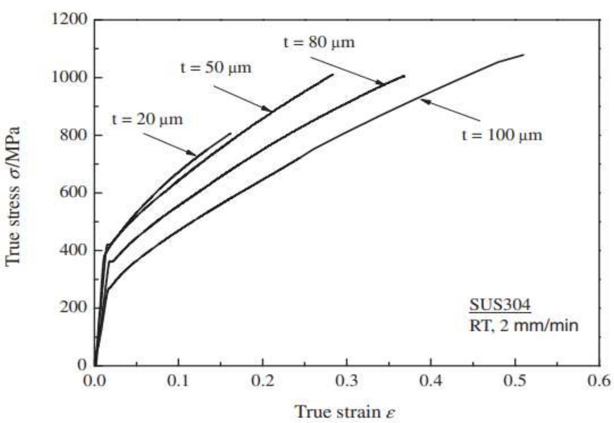


Fig. 3 Stress-strain curves of stainless steel sheets of different thickness [32]

The research method used in this work is theoretical research combined with numerical simulation and experiment.

B. Theoretical Basis in Micro-deep Drawing

1) Some influencing factors in the micro deep drawing: Many factors affect the results of stamping microscopic parts: the grain size, friction, and forming punch speed. Among them, grain size, especially the size of the grain compared to the thickness of the workpiece, plays an essential role in micro-deep drawing.

$$k = \frac{s_0}{l_G} \tag{1}$$

where k is the number of grains, s_0 is the workpiece thickness, l_G is the grain length. According to the Hall-Petch law [33], with micro-sized parts, the number of grains distributed over the thickness of the workpiece is tiny, so the yield stress of the metal increases as the size decreases, making it hard for the deformation process.

$$\sigma_y = \sigma_0 + \frac{K}{\sqrt{d}} \tag{2}$$

with d being the grain size and K being the number of grains, we have a chart showing the correlation between grain size (mm) and tensile strength (Mpa).

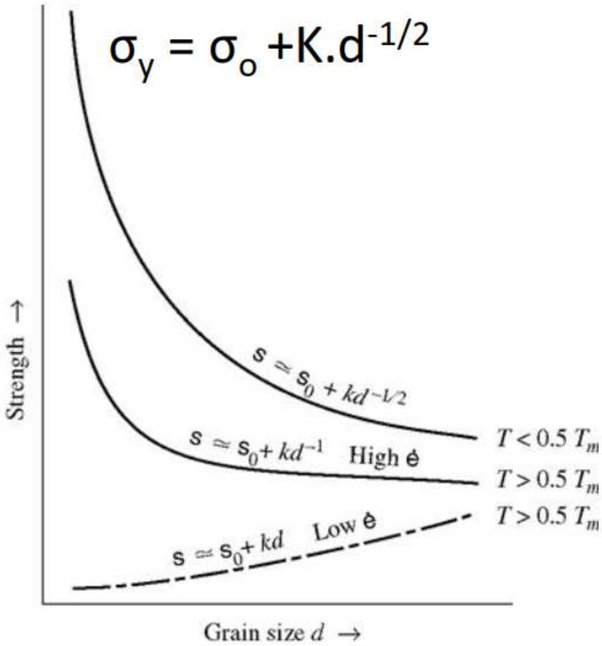


Fig. 4 Graph showing the correlation between grain size and tensile strength.

2) Theoretical basis for determining technological and geometric parameters: Determine the initial workpiece size: With the product's geometric parameters (Figure 2), the initial workpiece size is calculated according to the formula:

$$D_0 = \sqrt{d_1^2 + 2\pi r d_1 + 8r^2 + 4d_2 h} \tag{3}$$

Substituting the product's geometric parameters into expression 3, we will get the initial dimensions of the workpiece. $D_0 = 5\ mm$. Calculated stamping force: The level of deep drawing is one of the factors affecting the quality of stamped products. The degree of deep drawing is a measure of the metal's tensile ability [19], which is calculated by the ratio of the initial workpiece size and product size:

$$\beta = \frac{D_0}{d} \quad (4)$$

Then, the stamping force will be calculated according to the following formula:

$$F = d.\pi.s.R_m.n \quad (5)$$

where R_m is the tensile strength of the material. n is the adjustment factor depending on the level of drawing. We calculate the necessary stamping force: $F = d.\pi.s.R_m.n = 3.\pi.0{,}1\,.520.0{,}7 = 343\ (N)$

Geometric parameters of the mold:

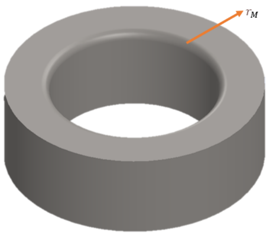


Fig. 5 3D model of drawing die

The fillet radius r_M is calculated according to the formula:

$$r_M = 0{,}035.[50 + (D_0 - d)] \cdot \sqrt{s} \quad (6)$$

with formula 6, the radius is $r_M = 1{,}77\ mm$. The 3D die shape is represented in Fig. 5.

C. *Establish The Simulation Problem*

From the calculated parameters, a 3D model of the connector head part micro-stamping die set was designed, shown in Figure 6. The stamping force is created by a pneumatic cylinder model SC32X150.

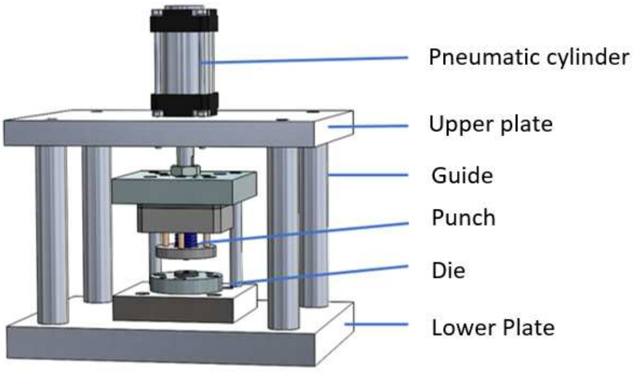


Fig. 6 3D model of connector head part stamping die set

The geometric model of the micro-cupping die with the *connector head part* in the simulation environment of Dynaformer software is shown in Fig. 7. It is assumed that the punch and die are rigid. Only the original workpiece (diameter 5 mm, thickness 0.1 mm) is considered deformable.

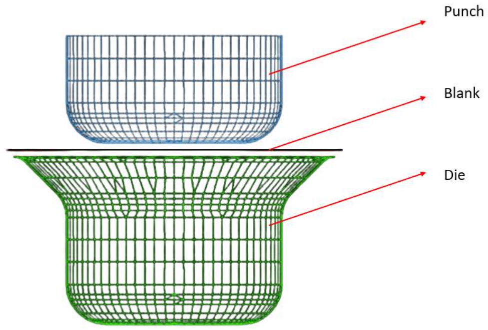


Fig. 7 The model assembly scheme in FEM

Set up boundary conditions for the simulation problem: the die is stationary, the punch pulls the workpiece inside the die, and when the punch goes all the way, the simulation process ends.

D. *Fabrication Of Experimental die*

From the results of theoretical calculations and simulation results, experiments manufactured a tiny deep drawing die for the connector head part to verify the calculated and designed parameters through theory and simulation.

Fig. 8 Experimental die

III. Results and Discussion

A. *Evaluate Forming Results*

The ability to shape the product, assessed through the FLD chart and product morphology, is shown in Fig. 9. Simulation results demonstrate that the shaped product is not torn (no red area) and tends to wrinkle at the edges. When the punch pulls the workpiece into the die, stress components will appear on the workpiece. The product is not torn because the material's stress remains safe. The body part tends to wrinkle because, before the workpiece slides through the mouth of the die, there is a compressive stress component in the tangential direction on the rim. Figure 9b also shows that the workpiece material at the rim is pulled entirely into the die cavity, creating a completed cylindrical cup shape.

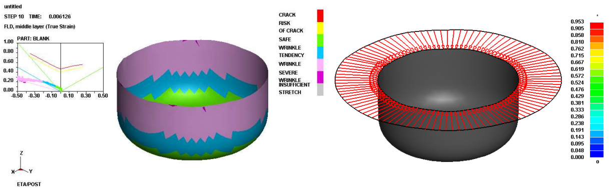


Fig. 9 Simulation results of wrinkles and tears of the product. a) Ability to create product shape; b) Ability to pull material into the die cavity

B. *Thickness Distribution*

Simulation results of thickness variation are shown in Fig. 10. The product thins the most at the fillet, and the degree of thinning was 6%. The thickness of the product body is almost unchanged. However, the thickness of the product edge has increased significantly at 26%. The unevenness in thickness on different areas of the part is due to the other stresses that occur when the punch pulls into the die. Part of the body has tensile stress in the axial direction.

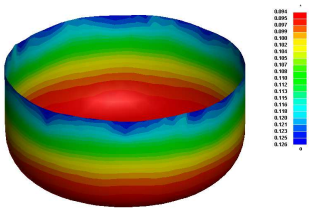


Fig. 10 Simulation results of thickness variation

Initially, the workpiece at the rim will have compressive stress in the tangential direction, so it becomes thick and then slides through the mouth of the die to form the part body. The thickness of the body will gradually decrease to reach the bottom fillet, where dangerous stress exists, causing thinning. However, this amount of thinning is still within the allowable limit of less than 30% of the original workpiece thickness.

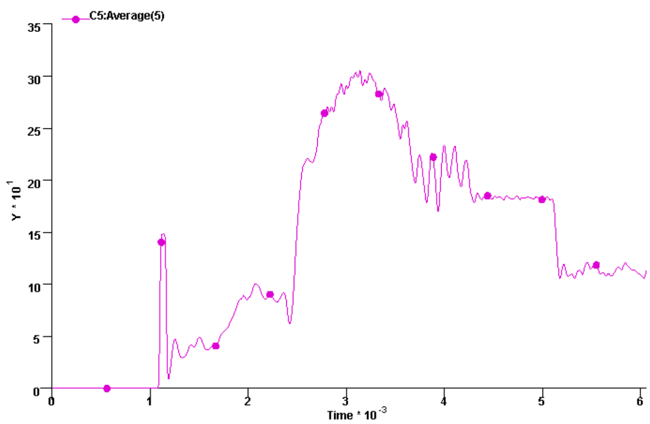


Fig. 11 Force graph of the deep drawing process

The most significant forming force determined through numerical simulation is 320 N, which is 6.7% smaller than that calculated by the proposed formula (5). This is because there are slight differences between actual and simulated conditions such as friction coefficient, material model, and meshing method, and this small value is entirely within the allowable range. The graph results show that when the punch pulls the workpiece into the die, the pressure is 150 N. Because wrinkles appear at the product's edge, pulling the workpiece into the die is more complicated. After that, the pressure increases, and the workpiece is pulled entirely into the die cavity. This is due to the deformation hardening of the material. This phenomenon of yield stress increases with the degree of strain during deformation. At the crystal level, dislocations constantly improve, and when moving, they will stagnate, as it is necessary to increase the stress to continue moving. The consequence is that the metal becomes more arduous, and to continue deforming, the force must increase. When the punch reaches the end of its stroke, the pressure gradually decreases, and the shaping process ends.

C. *Experimental Results*

The experimental product gives results similar to simulation results. The part was not torn or wrinkled. The rim part was uneven due to the anisotropy of the material. Thus, the proposed theoretical calculation to determine the technological and geometrical parameters of the mold in deep drawing microscopic cylindrical cup parts is appropriate.

Fig. 12 Experimental results

IV. CONCLUSION

With the technology of deep drawing micro-sized parts from sheet billet, the products are shaped with good quality and high productivity. The technological parameters and geometrical parameters of the workpiece and die have been determined using the calculation of the parameters proposed in this study. By numerical simulation and experiment, it has been shown that these parameters are entirely suitable for micro-meso deep drawing for cylindrical cup details. Research results are the basis for calculating and designing products with similar shapes applicable in electricity and electronics.

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