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Improvement of deep drawability by using punch surfaces with microridges

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ABSTRACT

Because of product miniaturization, demand for cups created by deep drawing has increased. However, because thin sheet materials exhibit poor deep drawing formability, using deep drawing on micro/meso cups is rather difficult. In this study, punch surfaces with microridges were used to enhance deep drawing formability. The concept was based on the observation that punch surfaces with microridges near the punch nose could disperse the drawing force of punches on sheet materials and delay the cracking of sheet materials. In this study, cylindrical cups composed of copper alloy were used. First, punch surfaces with microridges were designed and the Deform 2D software was used for analyzing the formability of deep drawing by using punch surfaces with and without microridges. Second, drawing dies were designed and produced, and an experiment was conducted to verify the results of the analysis. The study results indicated that commercial forming analysis software can be used to simulate the effect of microridges on deep drawability accurately. A comparison between the two punch surface types revealed that punch surfaces with microridges exhibited a slightly increased drawing force (3%) compared with those without microridges. Concurrently, the effect of punch surfaces with microridges increased forming height by at least 100%.

1. Introduction

The demand for electronics, information, and communication products has rapidly increased in recent years. In addition, development focuses on manufacturing compact and highly precise products. Because of strength and reliability concerns, the use of metal materials has increased noticeably after the miniaturization of various products. Micro/Meso products comprising a metal castings that are formed using deep drawing have advantages, such as high production efficiency, high product yield, and low manufacturing costs, and thus, the micro deep drawing manufacturing process is a micropart production technology bearing great potential (Geiger et al., 2001). Regarding micro deep drawing, Saotome et al. (2001) primarily investigated the micro deep drawing of sheet steel exhibiting a thickness of 0.2 mm or less. The experimental results showed that the limiting drawing ratio decreased as the punch diameter to sheet thickness ratio increased. Vollertsen et al. (2004) examined microforming from a tribological perspective. The results indicated that the coefficient of friction of micro deep drawing varied at the flange and the shoulder of cup and that the variations depended on the pressure exerted. The absolute coefficient of friction of micro deep drawing was higher than that of macro deep drawing. Marumo et al. (2007) conducted an experiment of micro deep drawing on stainless steel to determine the effect of foil thickness on blankholder force and limiting drawing ratio. The results revealed a significant effect of foil thickness and coefficient of friction on blank holder force. The limiting drawing ratio decreased as the foil thickness decreased. For a foil thickness less than 0.04 mm, the decrease in limiting drawing ratio was substantial, and the coefficient of friction exerted an extremely large effect on the limiting drawing ratio. Manabe et al. (2008) conducted a two-stage deep drawing process on cylindrical cups and investigated the effect of surface roughness on metal forming products. The results showed that the surface roughness of dies affected precision in the products and forming limits. In addition, surface roughness was significantly correlated with friction behavior. However, a die surface roughness less than 0.1 μm did not affect cup surface precision. Irthiea et al. (2014) performed an experiment and finite element analysis by using flexible tool techniques to investigate micro stainless steel cup forming.

The forming during micro deep drawing is heavily influenced by the grain size of materials when the size of the parts decreases,

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causing poor micro deep drawing properties. This phenomenon is called the size effect (Armstrong, 1961). Vollertsen (2003) divided size effect into that caused by physical sources or structural sources. Those derived from physical sources comprise the pure volume size effect, surface to volume size effect, and forces relation size effect, whereas those derived from structural sources consist of the grain size to thickness size effect and surface structure scalability size effect. Engel and Eckstein (2002) conducted a double cup extrusion test and determined that when the size of the parts was reduced to a micro-scale, the flow stress of the materials decreased as the size of the materials decreased. In addition, workpiece miniaturization resulted in increased friction. Coarse grains exhibited poorer formability than did fine grains, which is consistent with the results of related bending testing. Gau et al. (2007) performed tensile and bending testing on aluminum and copper alloys and observed that decreases in the specimen thickness to grain diameter ratio (T/D) lowered the specimen yield strength, stretch strength, and formability. Chan and Fu (2011) conducted tensile and extrusion experiments on various materials and discovered that the flow stress of materials decreased as the T/D value decreased and that workpiece miniaturization induced increased friction. In addition, Yeh et al. (2008) proposed a mathematical model for describing the behavior of materials in microforming as the thickness and grain size varied.

Recently published literature reports numerous efforts expended to improve drawability. In an experiment combining the micro deep drawing process and ultrasonic vibration, Huang et al. (2014) showed that increases in oscillation amplitude decrease deep drawing force and that the level of increase in the limit drawing ratio depends on foil thickness and oscillation amplitude. Yagami et al. (2007) examined the effect of controlling blank holder motion on the microdeep drawing process. They performed an experiment on cylindrical cups composed of a copper alloy and determined that wrinkles of more than 0.2 mm could be removed and that drawability was improved. Gau et al. (2013) performed an experiment entailing a micro deep drawing process and two ironing stages. The experimental results showed that the annealing of 0.2-mm-thick stainless steel 304 at 1050 °C produced an optimal forming height. These findings indicate that the size effect during the manufacturing process is influenced by the annealing temperature. Erhardt et al. (1999) proposed a warm forming microdeep drawing die concept by heating local parts of 0.1-mm-thick sheet metals using Nd/YAG laser irradiation during microdeep drawing. The results indicated that the punch force was reduced by at least 20%, and analysis revealed that formability was increased by 10%. Gong et al. (2011) performed a microdeep drawing experiment by using cylindrical micro cups as well as blank holders and lower dies coated with diamond-like carbon (DLC) films to reduce friction. The results showed that DLC films substantially decreased drawing force and increased the limiting drawing ratio.

The model of the deep drawing cylindrical cups is illustrated in Fig. 1. As shown in the left of Fig. 1, the blank is drawn by the punch into the lower die cavity together, and slides through surface of the blank holder and the lower die. Therefore, drawability can be enhanced by increasing the friction between the blank and punch, and by decreasing the friction between the blank and blank holder as well as the friction between the blank and lower die (Gong et al., 2011).

In this study, microridges were integrated to punch surfaces to increase the friction between blank and punch and to disperse the drawing force that punch exert upon the blank, thereby markedly improving the drawability shown in the right of Fig. 1. Cylindrical cups composed of copper alloy were used, and the study process is presented as follows: First, punch surfaces with microridges were designed and Deform 2D software was used for analyzing

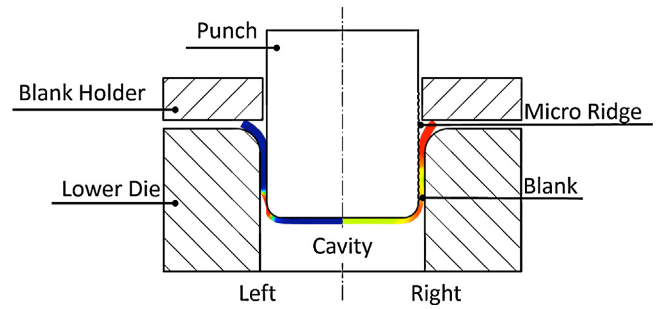

Fig. 1. Schematic of deep drawing.

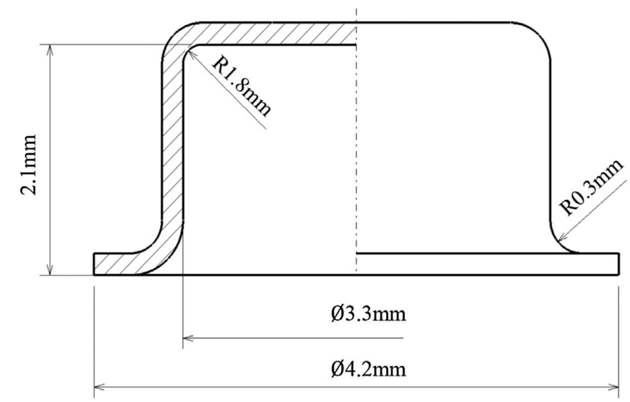

Fig. 2. Schematic of experimental component.

the formability of deep drawing by using punch surfaces with and without microridges. Second, drawing dies were designed and produced, and an experiment was conducted to verify the analysis results.

2. Design of punch surfaces with microridges

In this study, cylindrical cups composed of copper alloy and exhibiting an internal diameter of 3.3 mm, foil thickness of 0.2 mm, and depth of 2.1 mm were used. The parts were semi-finished products of laser diode copper casings. Fig. 2 shows the relevant dimensions of the products.

2.1. The mechanics of drawing influenced by the punch microridges

Fig. 3 shows the stress distribution of a blank during deep drawing performed with and without microridges punches. The figure shows that before the microridges contacted the blank (Depth = 0.56 mm), the stress distribution in the two blanks is identical.

Once the microridges contact the blank (Depth = 0.8 mm), the stress increases in both blanks. When drawing was performed using a punch without microridges, the punch nose radius determines the drawing force and friction force exerted upon the blank. When a punch with microridges was used in the drawing process, the clearance between the top of the microridges and the lower die was less than the thickness of the blank. Consequently, the microridges press into the blank. Therefore, the role of the punch in exerting drawing and friction forces upon the blank is divided between the nose radius and the microridges. Thus, the stress near the punch nose radius was slightly less when microridges were used.

As the punch continued to draw downward, the punches without microridges reached a depth of 1.227 mm; the stress near the punch nose radius increased significantly, and the thickness of