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Experimental and simulation studies of micro blanking and deep drawing compound process using copper sheet

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ABSTRACT

Microforming process is a promising micromanufacturing technology for producing microparts due to its high efficiency, low production cost and good product quality. The occurrence of size effect in the process, however, leads to the uncertainties in process determination, tooling design and product quality control and renders the design full of challenges. In-depth study of material deformation behavior in microforming process is thus crucial for development of quality microparts. In this research, the micro compound blanking and deep drawing of copper sheet is conducted. To investigate the size effect, the similarity theory is employed in die design and deformation process simulation. The grain size effect is studied by preparing the copper sheets with different grain sizes, while the feature size effect is also studied via using different punch radii. Based on the analysis of experimental results, it is found that the deformation load decreases with the increase of grain size, but this decrease is not significant when there are only a few grains in the cross section of the sheet metal. The deformation becomes inhomogeneous with the decrease of formed part size and the increase of grain size. This further leads to the irregular geometry and rough surface finish of the formed part. Furthermore, the simulation is carried out to reveal the entire deep drawing process. The deformation loads predicted by simulation have the same trend as the experimental ones, but the difference exists in-between. This indicates that the simulation of microforming process needs to consider the inhomogeneous deformation of material in the process.

1. Introduction

With the advance of microforming process in terms of the understanding of deformation behavior, process determination, and tooling design, microforming technology has become a more feasible, implementable, repeatable and controllable micromanufacturing process in recent years. The microparts with relatively small size, reliable structures, as well as the acceptable surface finish can be achieved nowadays. As a sub-set of micromanufacturing process, microforming is referred to the fabrication of parts or its feature with at least two dimensions in the sub-millimetre range via micro-scaled plastic deformation. It has a promising potential in mass production of micro components. Most typical microforming parts are leadframe, connector pin, IC-carriers, shaft of micro motor, etc. However, when the dimensions of parts are scaled down to micro/meso scale, the occurrence of size effect significantly affects the microforming process. The traditional knowledge in macroscale forming cannot be leveraged into the microforming process. Therefore, in-depth understanding of material deformation behavior and process characteristics is critical in design and development of micro-formed parts.

In tandem with the above-mentioned facts, many efforts have been made to the researches in microforming arena. Chan et al. (2010) have revealed that the flow stress decreases and inhomogeneous deformation occurs with the increase of grain size based on compression test using pure copper. Gau et al. (2007) conducted the tensile and bending tests of sheet metal to investigate the interactive effect of specimen size and grain size on material deformation behavior. It is found that the yield strength, tensile strength and stretchability (formability) decrease with the decreasing ratio of sheet metal thickness to grain size. Lai et al. (2008) established a constitutive material model for the change of flow stress with the specimen and grain sizes based on the surface layer model and Hall–Petch relation. In addition, Parasiz et al. (2007) found that the inhomogeneous deformation and irrational hardness distribution occur in the micro-extruded part when the grain size is in the order of micropart size. They also found the similar phenomena in micro-bent parts in the later research (Parasiz et al., 2010). To avoid the inhomogeneous deformation, Rosochowski et al. (2007) achieved the uniform material flow in the microextrusion experiment with ultrafine-grained material. Eichenhueller et al. (2007) investigated the microforming with a heating unit. They found that additional slipping systems of grains are activated with the increase

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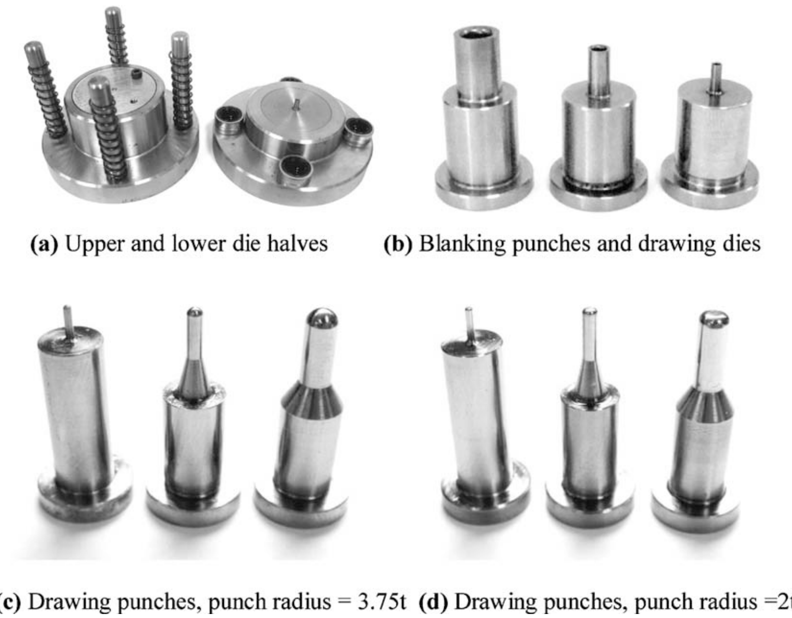

Fig. 1. Blanking and deep drawing compound tooling set. (a) Upper and lower die halves; (b) blanking punches and drawing dies; (c) drawing punches, punch radius = 3.75t; and (d) drawing punches, punch radius = 2t.

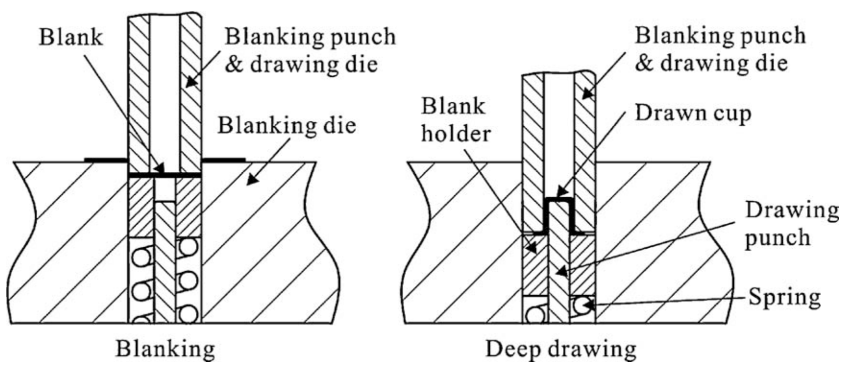

Fig. 2. Schematic illustration of the micro blanking and deep drawing compound process.

of forming temperature, which further results in more homogeneous deformation. Deng et al. (2011) carried out the researches into the influence of specimen size, grain size and the asperity size of material on the surface deformation behavior via compression of pure copper cylinder. It is found that the tooling–workpiece interfacial friction increases with the decrease of specimen size due to the increase of the real contact area (RCA). It is also concluded that the open and closed lubricant pockets result in the nonuniform deformation on material surfaces. Furthermore, Chan et al. (2011) conducted an investigation on different microextrusion processes. Their experimental results suggest that the grain size, part feature size and tooling–workpiece interfacial friction have a close relationship with the material flow behavior and deformation load. Therefore, the conventional friction evaluation methods might not be accurate in measurement of the friction coefficient in microforming systems.

Among the worldwide efforts, micro deep drawing process is also one of the focuses. Hirt et al. (2003) raised the critical issues

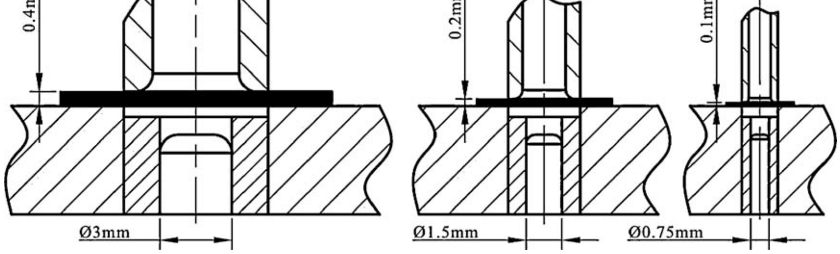

Fig. 3. Different size-scaled tooling sets and the corresponding blank thicknesses.