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Experimental and simulation study of deformation behavior in micro-compound extrusion process

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ABSTRACT

In micro-forming process, the prediction of deformation behavior is difficult as the conventional material constitutive model is no longer valid when the part geometry is scaled down to micro-level. This is caused by the so-called "size-effect". It is thus necessary to study the size effect and how it affects the deformation behavior in micro-forming process. In this research, a material constitutive model was established based on micro-compression test and its applicability was then studied. To facilitate the research, a flexible tooling set for micro-extrusion was designed and developed first. A modified micro-double cup extrusion test was proposed and the corresponding Finite Element Method (FEM) simulation was conducted. Through experiment and simulation, a set of deformation load curves were generated so as to provide a reference for calibration of flow stress–strain curve in modeling of micro-extrusion process. The applicability of the calibrated flow stress–strain curve was finally validated by the experimental and simulation results of micro-forward extrusion. It is therefore believed that the flow pattern, the material surface constraint and the material deformation mode are critical in determination of material flow stress curve. Furthermore, it was found that the change of cup height ratio of the extruded part is not caused solely by the change of friction when the part size is in micro-scale. The material flow stress significantly affects the cup height ratio. These findings provide a basis in understanding of micro-extrusion process.

1. Introduction

Miniaturization technology has become more and more important in micro-product development as it has been widely used in automotive, bio-medical, aerospace and consumer electronics industries. Currently, the micro-manufacturing technologies are classified into two categories. One is the lithography-based technologies and the other is the mechanical-based micro-manufacturing processes. Although the former is well established for semiconductor, micro-electronics and Micro Electro-Mechanical Systems (MEMS) fields, the same cannot be said to the latter, which includes micro-machining, micro-injection molding, micro-powder injection molding and micro-forming. Among these four mechanically-based processes, the first three have been well investigated, developed and used in industries. For micro-forming, however, it has not yet been systematically explored and studied in terms of process determination, tooling design, and defect prediction and avoidance. The micro-parts fabricated by micro-forming are defined as the plastic deformed components with at least two dimensions in sub-millimeter range. The knowledge on analyzing macro-forming process has been well developed [1,2] and it has been widely employed for supporting metal-formed product design and development [3,4]. When the part geometry is scaled down from macro- to micro-scale, the design and development of micro-parts fabricated by micro-forming cannot leverage the knowledge of macro-forming process to micro-forming since the size effect is a barrier to this knowledge transfer. Micro-forming process, due to its high productivity, high material usage, near-net-shape and the good mechanical properties of micro-formed part, presents a promising manufacturing process [5]. As the material deformation behavior in micro-forming is characterized by a few grains in deformation zones and the variations of grain size and mechanical property make the deformation behavior inhomogeneous and difficult to predict. Therefore, the understanding of material properties and deformation behavior in micro-forming process is critical in micro-product manufacturing by using micro-forming technology.

To realize this goal, researches on studying and modeling the deformation behavior in micro-scale have been conducted. Miyazaki et al. [6] found that dislocations are evenly distributed at the grain boundaries and inside the grain at the inner region of

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