International Journal of Machine Tools & Manufacture 60 (2012) 27–34

Contents lists available at SciVerse ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

Blanking clearance and grain size effects on micro deformation behavior and fracture in micro-blanking of brass foil

Jie Xu [a,b], Bin Guo [a,c], Chunju Wang [a,c], Debin Shan [a,c,*]

[a] Key Laboratory of Micro-Systems and Micro-Structures Manufacturing, Ministry of Education, Harbin Institute of Technology, 2 Yi-kuang Street, Harbin 150080, PR China
[b] Academy of Fundamental and Interdisciplinary Sciences, Harbin Institute of Technology, 2 Yi-kuang Street, Harbin 150080, PR China
[c] School of Materials Science and Engineering, Harbin Institute of Technology, 92 West Dazhi Street, Harbin 150001, PR China

ARTICLE INFO

Article history:
Received 18 October 2011
Received in revised form
14 April 2012
Accepted 16 April 2012
Available online 26 April 2012

Keywords:
Size effect
Micro-blanking
Micro-forming
Micro-hole
Brass foil

ABSTRACT

When the feature dimension of metal forming parts is scaled down to micro-scale, size effects occur and the understanding of micro-forming becomes complex. In this paper, the size effect on deformation behavior of brass foil was investigated via micro-blanking test. The results show that the ultimate shearing strength increases with the decrease of the foil thickness and the fracture mechanism of micro-blanking significantly changes from fracture mode with ductile dimples. There exists a minimum peak value during micro-blanking of brass foil over the considered relative blanking clearance range. However, the deformation behavior of micro-blanking process not only relates with the blanking clearance, but also relates with the grain size of brass foil. The grain size has a significant influence on micro-blanking and the curves of coarse-grained foil specimen show a strong variation not only in the curve profile but also in blanking edge distribution. To explain the size effect mechanism of micro-blanking, a size effect model of micro-blanking was established by considering the blanking clearance and grain size and the results indicate that the ratio of blanking clearance to grain size is one of the main factors to affect micro deformation behavior in micro-blanking. The ultimate shearing strength reaches an extreme value when the blanking clearance to grain size ratio is equal to 1.

1. Introduction

With the development of micro-electromechanical system (MEMS), micro-parts including micropins, miniature screw, micro-gear, integrated circuit (IC)-socket, micro-holes, etc., are widely used in the field of microelectronic, printing and dyeing textile, bio-medical devices and aerospace [1]. Compared with MEMS-based manufacturing technology such as lithography etching process, micro-forming is one of suitable approaches to fabricate micro-parts due to the advantages of high productivity, low cost, near-net-shape and excellent mechanical properties [2]. However, when the feature size of micro-parts is reduced from macro-scale to micro-scale, the plastic deformation behavior is determined by only a few grains located at the deformation regions and size effects occur [3,4]. The conventional material models are no longer valid in the analysis of deformation behavior of micro-forming [5,6].

In order to investigate size effects in micro-forming, a lot of researches have been conducted. Geiger et al. [7] presented a keynote paper on micro-forming in 2001 and conducted a comprehensive review of micro-forming technology. Saotome et al. [8] established a size effect model to explain the difficulty associated with feature dimensions of micro components that are smaller than the grain size of polycrystalline materials. Geiβdörfer et al. [9] proposed a meso-scopic model by considering the grain boundary condition and anisotropic material behavior to simulate the size effect in micro-upsetting test. Zhao et al. [10,11] described the size effect on fracture behavior based on the composite model concerning the grain boundary and grain interior. The results show that the failure mode changes gradually from shear to normal tensile failure with the increase of specimen thickness. Kang et al. [12] investigated the micro-formability of Al5083 with micro-forging process. The results indicate that the micro-formability increases with the decreasing grain size. Wang et al. [13] found that the groove size of die and the grain size of material significantly affect the material micro-formability in micro-coining test. Kim et al. [14] investigated the feature/specimen size effect with a scaling model by introducing two parameters to the Hall–Petch equation. Fu et al. [15] established surface layer models with the identified surface grain, the internal grain properties and the measured friction coefficients and provided an in-depth understanding of size effects on micro-scale deformation and frictional phenomenon via micro compression test. Peng et al. [16,17] established an elastic-plastic constitutive model and a

* Corresponding author at: Key Laboratory of Micro-Systems and Micro-Structures Manufacturing, Ministry of Education, Harbin Institute of Technology, 2 Yikuang Street, Harbin 150080, PR China. Tel.: +86 451 86402775; fax: +86 451 86418732.
E-mail address: shandb@hit.edu.cn (D.B. Shan).

0890-6955/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijmachtools.2012.04.001

uniform size dependent constitutive model to investigate the size effect in thin sheet micro-forming process. Wang et al. [18] proposed a new constitutive model considering the first order size effects for micro sheet metal forming combining the Hollomon equation and Hall–Petch relationship. Mahabunphachai and Koç [19] developed a new material mode with the characteristic parameters of relative size between grain size, thickness and the part feature by using hydraulic bulge test. Zheng et al. [20] investigated the size effect of metal foil with micro scale laser bulge forming. The results show that the deformation depth decreases with an increase of specimen thickness, while it becomes larger as the enhancement of laser energy. Chan and Fu [21] studied the geometry and grain size effects on fracture behavior of sheet micro-forming process and developed a dislocation density models considering the interactive effect of specimen and grain size on fracture stress and strain, which was verified with experimental results. Ma et al. [22] investigated the size effect on fracture behavior in deep drawing process. The results show that the limit drawing ratio is significantly decreased with grain size. Manabe et al. [23] investigated the size effects in micro-deep drawing based on the surface roughness model. Kals and Eckstein [24] studied the size effects in tensile test, air bending and micro-blanking of sheet metal by means of miniaturization methods according to similarity theory. They found that the deformation behavior in micro-punching strongly differ from those in both the tensile test and air bending. Further research of Raulea et al. [25] showed that the yield strength is related with the ratio of grain size to specimen thickness and a strong increase of variation occur with the increase of grain size, which is also demonstrated in a planar blanking process. Joo et al. [26] studied the size effect in micro-punching process. It is indicated that when there are only a few grains cross the foil thickness, the conventional ductile fracture by crack initiation and propagation does not occur and the shear deformation is dominated along the micro-hole wall. Xu et al. [27] investigated the size effects in micro-blanking of metal foil with miniaturization and the results show that the ultimate shearing strength of micro-blanking is decreasing with the increasing of the length scale.

Among the prior studies, it can be seen that the size effects in micro-forming are only limited to few individual factors. However, multi-factors including mould dimensions, process conditions and material properties actually interplay and interact in size effects of micro-forming. These factors should be considered simultaneously during the experiment and theoretical analysis. In the study, micro-blanking tests of brass foil were conducted and the influence of mould clearance, specimen geometry and grain size on the deformation and fracture behavior was investigated. Based on the experimental results, a size effect model of micro-blanking was established by considering blanking clearance and grain size. This paper is aimed to conduct an in-depth research of deformation and fracture behavior in micro-blanking process.

2. Experimental preparation and conditions

2.1. Micro-blanking tools

Micro-blanking apparatus was designed and the schematic illustration of die assembly was shown in Fig. 1(a). In order to provide the flexibility to conduct the different micro-blanking processes, the female die and micro-punch with different feature dimension can be changeable in one micro tool. A high strength tungsten carbide DC-750 with ultrafine grain of 0.6 μm was adopted as micro-punch material. The micro-punch is fabricated with high dimensional accuracy of ±1 μm by micro-grinding and finished with high surface quality by ion beam irradiation [28] as shown in Fig. 1(b).

2.2. Specimen preparation

2680 brass foil is selected as the experimental material due to the wide application in industries. The as-received brass foils have the thickness ranging from 40 to 200 μm. The specimens were annealed at the temperatures ranging from 350 to 750 °C at Ar air protection condition for 1 h to obtain different grain sizes.

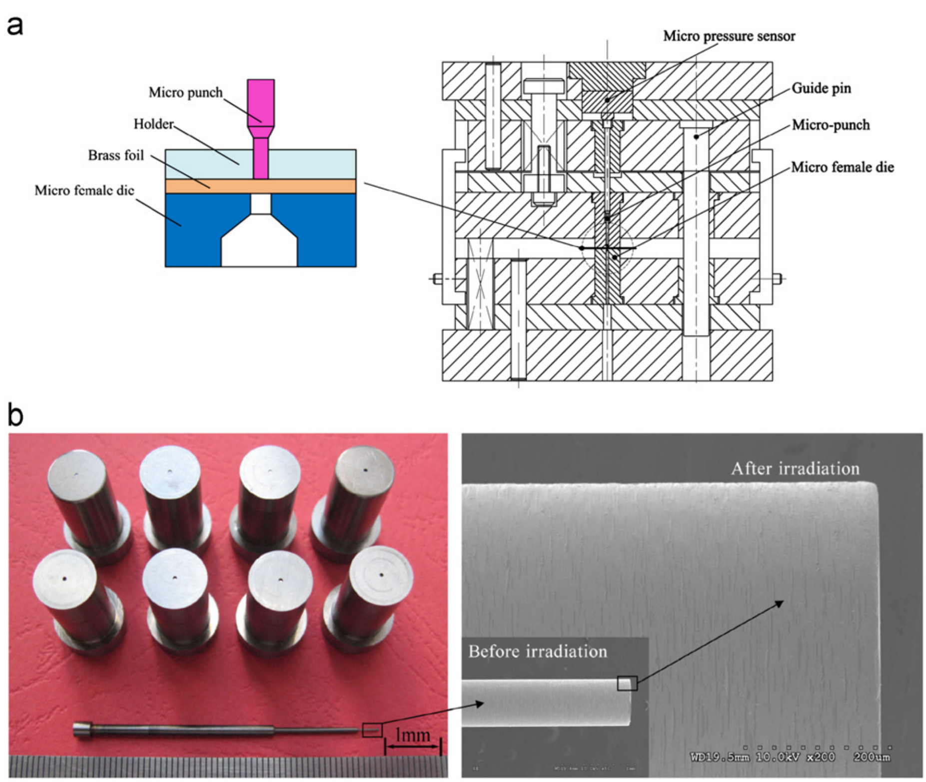

Fig. 1. Micro-punching tools. (a) Schematic illustration of die assembly and (b) micro-punch and female die.