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Effect of nano-crystals at surfaces induced by ion beam irradiation on the tribological behaviour in microforming

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

[a] School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, PR China
[b] Key Laboratory of Micro-systems and Micro-structures Manufacturing, Ministry of Education, Harbin Institute of Technology, Harbin 150001, PR China

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ABSTRACT

To realize the effect of surface topography on tribological behaviour in microforming, the surface of a copper thin sheet was modified using ion beam irradiation equipment to change the micro-topography of the surface. The surface quality was evaluated by the surface roughness using SEM and AFM. A serial of strip drawing experiments were carried out to analyse the effect of surface modification on the tribological behaviour. Then, the modified specimens were applied to micro-cup deep drawing process of 1.1 mm in diameter. The results show that the surface roughness (Ra) decreases and many nano-crystals are induced by ion beam irradiation. The surface with many nano-crystals is helpful for storage of lubricant oil to bear high pressure. With the modified specimen, the punch load in micro-deep drawing process is lower than that with original sheet. This can be analysed by the hypothesis of the Wanheim/Bay model. The results indicate that surface modification using ion beams can be used to decrease friction in small contact area.

1. Introduction

More attention has recently been focused on the microforming process which is very suitable for low cost massive production of micro-parts used in micro-electro-mechanical systems (MEMS) and micro-systems technology (MST) [1]. During the scaling down of micro-parts, the coefficient of friction (COF) increases rapidly, and a scaling effect of friction occurs when the liquid lubricant oil is applied [2,3]. The friction factor increased from 0.02 for the 4 mm specimens up to 0.4 for the 0.5 mm specimen using extrusion oil [4], and the results have been analysed by the developed "closed-open lubricant pockets" model [5]. Then, the size effect in friction was described quantitatively by a function developed from Wanheim/Bay model [6,7]. In sheet metal forming, friction functions were developed to integrate into a FEM simulation program [8,9]. Considering surface roughness of thin sheet, a model was developed and validated by micro-deep drawing [10]. Then, structured mould surfaces were applied and led to a decrease in friction for the reduction of the adhesion forces in the contact area [11]. In simulation of metal forming processes, an approach was sought to describe the friction by modelling the geometric surface roughness of the tool [12].

In this investigation, the surface of T2 copper thin sheet was modified using ion beam irradiation. Effects of surface modification on the friction coefficient were analysed with strip drawing tests. The micro-deep drawing process was carried out using a multiple operation mould with the modified specimen. A serial of micro-cups of 1.1 mm in diameter were fabricated successfully. The tribological behaviour during deep drawing was analysed based on the Wanheim/Bay model.

2. Experiment setup

A T2 copper thin sheet of 40 μm in thickness was selected as the experiment material for its excellent properties. The purity of T2 copper thin sheet is 99.9 wt.% as shown in Table 1. The thin sheet was annealed at the temperature of 600 °C for 12 h in the nitrogen gas atmosphere. After that, an electron cyclotron resonance (ECR) ion beam irradiation equipment (Elionix Inc., EIS-200ER) [13] was selected to modify the surface of the thin sheet. The irradiation rate not only depends on the atomic weight of ions and chemical bond of the material, but also on energy, density and incident angle of the ions. In the investigation, the parameters of ion beam irradiation are adopted as shown in Table 2. Since the beam intensity of the ion beam is not uniform, the specimens were rotated with a velocity of 1 rev/min to get uniform ion irradiation. The surface topography was evaluated using the surface roughness which was obtained by AFM (DI, Dimension3100).

* Corresponding author. School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, PR China. Tel./fax: +86 451 8641 8640.
E-mail address: cjwang1978@hit.edu.cn (C. Wang).

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Table 1
Chemical composition of T2 (wt.%).

Cu	Bi	Sb	Pb	As	S	O
≥99.90	≤0.002	≤0.002	≤0.005	≤0.002	≤0.005	≤0.06

To investigate the tribological behaviour of the modified thin sheet, a coefficient of friction evaluation method was developed with a strip drawing between two opposing flat punch surfaces which were wider than the strip as shown in reference [14]. The friction and normal force are measured with a Transcell FAS sensor of maximum range 300 N and a Transcell BAB sensor of maximum range 500 N, respectively. The measurement accuracy of sensors is 0.03% of maximum range. Micro-cup deep drawing experiments were carried out with the modified thin sheet of 40 μm in thickness using the developed blanking/deep drawing multiple operation mould [15]. The diameters of the blanked specimen D and formed micro-cup d are 2.0 mm and 1.1 mm, respectively. Then, the limited drawing ratio (D/d) of micro-cup is 1.8. The punch load was directly obtained by a small sensor embedded in the mould.

3. Results and discussion

3.1. Improvement of surface quality

SEM topographies show that the surface quality is improved obviously by the ion beam irradiation. On the original surface, there are many micro-scratches with sharp tips which are induced during fabrication of thin sheet. After ion beam irradiation, the sharp tips were eroded by the ion beam, and the micro-scratches became smooth. With increasing irradiation time, the surface of the specimen was polished to make it more smooth. The surface roughness is reduced by the ion beam irradiation. The results of AFM show that RMS roughness decreases from Ra 0.2 μm for the original surface to Ra 0.186 μm for 15 min and Ra 0.116 μm for 30 min, respectively.

Table 2
Condition of ion beam irradiation.

Ion beam conditions	Values
Ion	Ar^+
Accelerating voltage (V)	800
Pressure (Pa)	1.0×10^{-4}
Ion current density (mA/cm^2)	1.2
Irradiation angle θ (°)	30°
Irradiation time (min)	15, 30
Rotation speed of specimen (r/min)	1

3.2. Nano-crystals at specimen surface

To analyse the surface topography of the specimen, its surface was observed in magnified images at different positions, such as centre point, middle point at distance 7 mm from centre point and a point at the rim a distance 14 mm from the centre point. It can be seen that micro asperities at the original surface grow to nano-particles due to the high energy of ions as shown in Fig. 1. Since the cross-section of ion beam is about 30 mm in diameter, the beam intensity is larger at the centre points than that at the rim of ion beam area for the edge effect as shown in Fig. 2. The dimension of nano-particles is much bigger than that at the edge. The diameter of nano-particles increases from about 100 nm for rim point to about

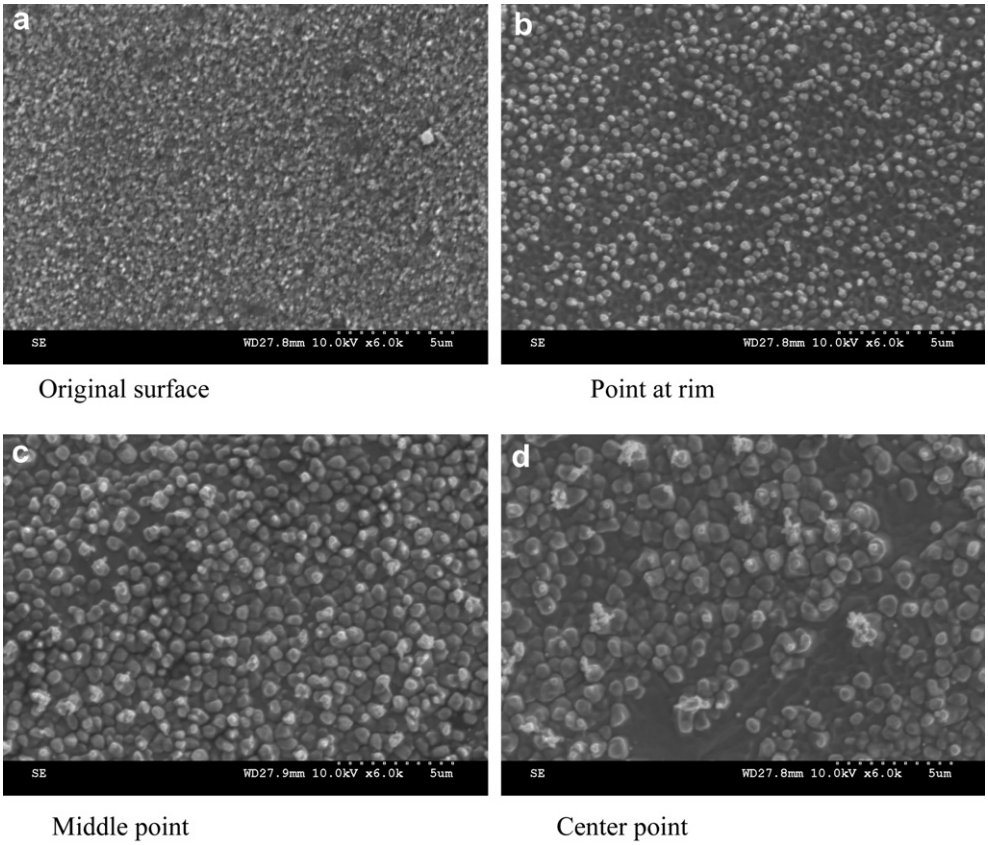

Fig. 1. Nano-particles at original surface and after 30 min (a) original surface, (b) point at rim, (c) middle point, (d) centre point.