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Improving the Formability of Metals in Microforming

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Abstract

Microforming is effective to economically and precisely manufacture metallic micro products that have extensive applications in medical devices, precision equipment, communication devices, micro-electromechanical systems and micro fluidics systems. However, the formability of metals in microforming would be greatly impacted due to the unique characteristic of size effects existed in microscale. This paper has introduced the approaches that are applicable to the improvement of formability of metals in microforming, which will be helpful for those who are studying and working on metallic micro products and their microforming technologies.

Keywords: Microforming; Formability; Size Effects; Metals

Introduction

Microforming is a promising and cost effective approach to produce complex metallic micro products for a diverse range of applications including medical devices, precision equipment, communication devices, micro-electromechanical systems and micro fluidics systems. In metal forming, the theories and technologies on forming processes in macro scale have been well established and widely used to manufacture high quality complex-shaped parts with highly sophisticated multi-stage tools, making the forming of several geometrical features at an individual part possible. The conventional forming process has been thought to be an appropriate choice for the economical and reliable manufacturing of a variety of metal components in the large-scale production. Unfortunately, metal forming theories and technologies established in the macro world cannot be simply scaled down to the micro world, because it is impossible to scale down all parameters in the microforming process according to the theory of similarity due to the size effects, which are well known as a unique characteristic with miniaturisation [1,2]. As a result, the formability and forming behaviour of a miniaturised part in microforming no longer follow the conventional rules established in macroscale metal forming process.

Size effects can be categorised into four types, namely density size effects, shape size effects, microstructure size effect, and tribological size effects [3]. Size effects occur due to the fact that the ratio among all decisive features cannot be kept a constant according to the process requirements. Size effects may cause a number of unexpected problems in microforming process in the aspects of mechanical behaviour, tribology, and scatter of material behaviour, which have significant impact on the formability of metals in microforming. Therefore, appropriate control strategies of size effects should be adopted with the purpose of improving the formability of metals in microforming, and finally the quality of formed parts. This paper introduces the approaches that are applicable to improve the formability of metals in microforming.

Approaches for Improving Formability

Forming at elevated temperatures is commonly used to improve the formability of metals in microforming. Heat-assisted microforming is an effective process to counteract inhomogeneous deformation and improve the accuracy of formed parts. During forming at elevated temperatures, additional slip systems are activated with the effect to reduce the dependency on single grains. This improves not only the material flow but also the reproducibility of process variables like flow stress. Further, temperature also leads to a reduced scatter of process parameters such as the force-stroke characteristic. A moderate increase of forming temperature can lead to a significant reduction of the scatter problem occurred in the microforming process of metals, and thus can significantly improve the process stability and reliability [3]. In the conventional metal forming under assistance of heating, the mechanical behaviour of material is sensitive to temperature due to the occurrence of microstructural phenomena including grain growth, surface oxidation, and friction condition. However, when heating is applied to the microforming process, the actual forming temperature in a miniaturised workpiece would be lower than the preset value as the surface-to-volume ratio increases, which enhances heat transfer to the atmosphere. With consideration of micro dimensional size of workpieces, heating temperature should be controlled within a certain range in case of excessive grain growth and oxidation of metal workpieces. Warm forming is a sensible option to improve the formability and to avoid oxidation. In practice, the upper limit of warm forming temperature is usually determined by the amount of oxidation which can be tolerated, and its lowest limit is determined by a force which can be measured using the forming machines and the material formability. Laser heating and resistance heating are two heating methods that are commonly used in heat-assisted microforming process of metals. Differently, laser heating has a number of advantages as compared to resistance heating [4]:

i. The laser energy input and thus the resulting temperature in the workpiece can be easily controlled via the current of a diode laser;

ii. Local heating of selected areas of the workpiece is possible, allowing to limit the heating to the forming zone;

iii. Needed temperature gradients can be achieved by control of laser power;

iv. The absorption of laser radiation allows short processing time which cannot be accomplished with heat transfer from pre-heated tools; and

v. Material properties can be manipulated by controlling the down cooling time via laser power.

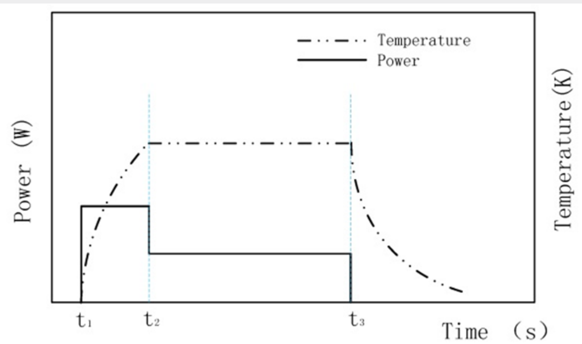

Figure 1: Laser heating strategy and specimen temperature.

The nature of laser heating is to change the internal microstructure of metals by energy absorption. The metals absorptivity of laser light is a critical factor that influences the deformation process. When a metal specimen is heated up to the expected temperature prior to microforming process, significant heat loss will be caused due to the relatively large ratio of specimen surface to volume. During deformation, the laser power should be adjusted to an appropriate value to compensate the energy loss due to heat convection and radiation from specimen to atmosphere which is especially significant in microforming. Figure 1 demonstrates a strategy of laser heating during microforming process. Micro specimen is first heated up from t_1 to t_2, and then the deformation begins. In this way, the temperature could be kept nearly a constant because of heat compensation of laser throughout the whole microforming process (from t_2 to t_3). The actual temperature of heated specimen can be measured using an infrared thermometer.

An alternative approach for improving the formability of metals in microforming is microstructural refinement. A typical work on micro extrusion indicates that grain size effects on deformation load are sensitive to the friction force attooling-workpiece interface in micro extrusion process [5]. Coarse grains will induce inhomogeneous deformation of metals. This phenomenon is thought to be caused by the fact that anisotropy grain properties become significant when only a few grains flow into the micro-sized cavity, resulting in an irrational local deformation. A large number of slips pass through the grain boundary toaccomplish the strain continuity in the case of coarse grains, and will cause the blurred grain boundary. The benefits of microstructural refinement in the reduction of size effects and improvement of formability have been confirmed by a large number of scholars in different microforming processes [6-11]. Severe plastic deformation is a processing method by which the grain size can be reduced sufficiently to retain a high thickness to grain size ratio, and is widely used in microstructural refinement. Equal channel angular pressing (ECAP) is a severe plastic deformation processing technique that is useful in obtaining an extremely fine grain structure - often at submicron or nanometre scale - and achieving a significant improvement in strength of the material. ECAP can produce a variety of ultrafine-grained microstructures in materials depending on route, temperature and number of passes during processing, and is commonly used in combination with microforming to improve the formability of meals and the quality of formed parts.

Conclusion

Size effects characterise the micro world, and have significant impact on the formability of metals in microforming and the quality of formed parts. In this paper, two approaches, including forming at elevated temperatures and microstructural refinement, that are commonly used to improve the formability of metals in microforming have been introduced. In order to improve the formability of metals in microforming and take full advantage of microforming technology, understanding of the mechanisms of size effects is essential. If appropriate control strategies of size effects are adopted, the formability of metals in microforming can be significantly improved, and microforming can be a promising method for manufacturing high quality micro products with high production rates, excellent material utilisation and low costs.

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