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学位論文題名	Investigation on Material Deformation Behavior of Thin Pure Titanium Foils in Microforming Assisted by Resistance Heating （通電加熱を用いたマイクロ塑性加工における純チタン箔材の変形特性に関する研究）
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【論文の内容の要旨】

Microparts are widely used in micro-electromechanical systems (MEMS) such as micro springs for electronics, tweezers for surgery, and micro gears in wristwatch. Pure titanium (Ti) is often used for the manufacture of microparts in biomedical devices and implants because of its light weight, biocompatibility, and outstanding corrosion resistance. Due to its high productivity, near-net-shape, and good properties of the formed products, microforming has been received much attention in the manufacture of microparts. However, the material flow becomes inhomogeneous and the process is unpredictable when the size is scaling down. In addition, the conventional plastic theory such as material properties cannot be used directly for the manufacture of microparts due to the occurrence of size effects in microforming.

Heat assisted microforming is an effective way to reduce size effects in microforming process. Moreover, resistance heating (RH) method is an effective approach to improve the heating rate and reduce the consumption of energy. By conducting microbending process assisted by RH, the springback was found to decrease with increasing temperature. Even though microforming processes, such as micro deep drawing and microbending were conducted with pure Ti foils at elevated temperatures by RH method, the mechanical properties of thin pure Ti foils at elevated temperatures

and the size effects of heat on the mechanical properties are not clarified yet. In addition, the mechanism of springback behavior for thin foils bended at elevated temperatures and the size effects of heat on the springback are also not clear. These unclear fields make the design of RH-assisted microforming process difficult. Within the above background, this study aims to clarify the mechanism of material deformation of thin pure Ti foils at elevated temperatures and contribute to the design of RH-assisted microforming process. To achieve this, a tensile testing system assisted by RH is newly developed to investigate the tensile properties of thin pure Ti foils and to investigate the size effects of heat on the tensile properties. To clarify the mechanism of springback behavior of the foils and to investigate the size effects of heat on the springback, microbending tests assisted by RH are performed. To contribute to the prediction of springback, the analysis of springback of the foils is conducted by using the obtained material properties. A new theoretical model is proposed to predict the springback angle of thinner foils after bending at elevated temperatures. In addition, the influence of temperature distribution on material deformation in microforming assisted by RH is investigated by commercial software ABAQUS to contribute to the design of the process. It is found that temperature has more influence on the foils with larger grain size. Compared with thick foils, the less springback of thinner foils observed at elevated temperatures indicates better accuracy of the products. The predicted springback angles by theoretical analysis using the proposed model show good agreement with experimental results, which confirms the feasibility of the new model. Moreover, the design and optimization of temperature distribution can be realized by numerical analysis using ABAQUS. Being composed of six chapters, the introduction and main achievements of this study are summarized below.

Chapter 1 introduces the background of microforming. Based on the issues in microforming, the motivation and objectives of this study are stated.

Chapter 2 investigates the material properties of thin pure Ti foils. A tensile testing system assisted by RH is newly developed. Uniaxial tensile tests are carried out at different temperatures for the foils with different thickness by using the developed system. The material properties of thin pure Ti foils are investigated. Relationships among strain hardening, strain rate sensitivity, and electric current density (ECD) are described. Grain size effects of heat on the material properties of thin pure Ti foils are discussed.

Chapter 3 investigates the springback behavior of thin pure Ti foils after bending at elevated temperatures. Scaled microbending tests assisted by RH are performed to investigate the springback behavior for the foils with different thickness. The less springback of thinner foils observed at elevated temperatures indicates better accuracy of the products. To clarify the mechanism of springback, Nanoindentation tests are conducted. The more influence of surface area during bending at elevated temperatures is suggested to be the reason for the more decrease in springback of thinner foils. To investigate the grain size effects of heat on the springback, microbending tests are performed by using annealed foils with different grain sizes. The springback angle is found to decrease with increasing grain size, and the reduction of springback angle shows the tendency that increases with increasing grain size. The mechanism and size effects of heat on springback behavior are discussed.

Chapter 4 conducts the numerical and theoretical analysis of the springback behavior of thin pure Ti foils in RH-assisted microbending. To predict the springback angles for thinner foils, a new theoretical model that the surface area increases with increasing temperature is proposed. The calculated springback angles by using the proposed model for thinner foils show good agreement with experimental results, which confirms the feasibility of the proposed model. To discuss the influence of strain gradient on the springback, a composite constitutive model involving statistically stored dislocation and geometrically necessary dislocation is established. The strain gradient induced in microbending influences the springback of the foils significantly at low temperatures, while the size effect caused by strain gradient decreases with increasing temperature due to the more homogeneous material flow.

Chapter 5 investigates the influence of temperature distribution on material deformation in microforming process assisted by RH. Finite element (FE) models for the numerical analysis of micro deep drawing process assisted by RH are developed. It is found that the temperature distribution of the blank is caused not only by the difference in ECD of the foils, but also by the heat transfer from the material to the tools. The design and optimization of temperature distribution can be realized by using the developed FE models. The influence of temperature distribution on material deformation can be obtained successfully.

Chapter 6 summarizes the whole thesis. The innovation and contribution of this study is presented. The remaining problems and future works are suggested.