Finite Element Simulation of Repeated Upsetting at Elevated Temperature

Wei Guo1, *, Jin Zou1, Keming Liu2
1 Institute of Applied Physics, Jiangxi Academy of Sciences, Nanchang 330096, China
2 Jiangxi Key Laboratory for Precision Drive and Control, Nanchang Institute of Technology,
Nanchang 330099, China

*E-mail: guoweii66@sohu.com

Abstract. The equivalent strain field, effective stress field, and temperature field of the billet after repeated upsetting were analyzed by using finite element simulation software. The results show that the average equivalent strain in the billet improves with the increase of processing pass. At the same pass, the strain in the middle of upper surface is the smallest and in the middle of lower surface is the largest. After three passes, maximum strain of 5.33 is achieved. The equivalent stress and temperature decrease gradually from the middle to both sides of the billet.

1. Introduction
In recent years, the technology of severe plastic deformation has been paid more and more attention by researchers and developed rapidly[1]. There are many factors influencing the effect of severe plastic deformation, such as die structure, processing path, preparing temperature, forming speed, friction coefficient between material and die, etc[2-4]. It takes a lot of manpower and material resource to systematically study the effect of different processing technology on material through experiment. With the rapid development of computer technology and finite element software, it is a shortcut to use numerical simulation to analyze the process of severe plastic deformation by establishing models. The finite element analyses for equal channel angular extrusion, high pressure torsion, accumulative roll bonding and reciprocating extrusion have obtained a lot of useful results[5-8]. Repeated upsetting is a novel severe plastic deformation method, and the remarkable effect of this technology on refining microstructure and improving mechanical properties of Mg alloy has been reported[9-11]. However, the finite element analysis of this technology is still lacking. In this paper, the simulation of repeated upsetting is carried out by using finite element software, and reference is provided for the practical application of this technology.

2. Research procedures
Fig.1a is the sketch map of repeated upsetting process. The device consists of a punch with dimension of 150 × 100 × 20 mm³ for external loading, a billet with dimension of 100 × 100 × 20 mm³, and a die with external dimension of 165 × 180 × 180 mm³. The lower chamber of the die and the billet are of equal dimensions. The simulation of repeated upsetting was carried out by finite element software and three-dimensional models were established. The finite element meshing of the processing device was shown in Fig.1b. The material model of billet was Al-1100 in the database of the software itself, which was defined as a plastic body. The meshing of the model was automatically generated by the software with three-node isoparametric elements. Upsetting process was numerically simulated and the mesh was self-adaptively re-divided. The material of punch and die was H-13 steel, which was defined as rigid
body and meshed to facilitate the analysis of heat transfer between punch and billet. For plastic deformation hardly occurred in the punch and die, larger finite element meshes were divide for them. The upsetting temperature of simulation was set to 400 °C. The friction between the billet and die was modeled as shear friction and the friction coefficient was set at 0.3. The downward speed of the punch was 4 mm/s during upsetting, and three processing passes were made. After the first pass was simulated, the billet was taken out and rotated 90° around the X-axis and replaced into the die cavity. Then the simulation results were imported into the pretreatment module of the next upsetting pass and the second pass was carried out. In the same way, the third upsetting pass was completed. In the post-processing module, the values and distributions of strain, stress, and temperature in the billet after upsetting were obtained.

Figure 1. (a) Sketch map and (b) finite element mesh generation of repeated upsetting device

3. Results and analyses

3.1. Strain field
The strain distribution in the billet after repeated upsetting for one, two and three passes are shown in Fig.2a, Fig.2b and Fig.2c, respectively. The strain presents gradient distribution from the middle to both sides. High strain distributes in the middle position of the bottom, due to this part deforms from the beginning to the end of upsetting. With the increase of passes, the maximum equivalent strain in the billet increases from 2.37 to 5.33. The low strain mainly distributes in the middle part of upper surface, for this part begins to deform just before the end of upsetting. With the increase of passes, the minimum equivalent strain value increases from 0.708 to 3.49. The increase of the strain value indicates that the microstructure of the billet will be gradually uniformed and refined. In addition, the side of the billet changes from flat to a certain radian, the edges and corners become more and more obscure with the processing pass.
Figure 2. The strain distribution in the billet after repeated upsetting for (a) one, (b) two, and (c) three pass

3.2. Stress field
As shown in Fig. 3, the effective stress distribution in the billet after one pass upsetting is between 10.8 MPa and 45.1 MPa. The highest stress distributes at the edge contact between the billet and the punch, which is directly affected by the die at the corner. The medium-sized stress alternately distributes in the billet from the middle part to both sides.
Figure 3. Distribution of effective stress (MPa) in the billet after one pass upsetting

3.3. Temperature field
The temperature distribution in the billet after one pass upsetting is shown in Fig. 4. It can be seen that the temperature presents a remarkable gradient distribution. The temperature of the punch contact area is the highest, reaching 411 °C, due to the heat generated by the friction between the billet and the die. The temperature decreases gradually along the edge of the billet, and the lowest temperature at the corner is 404 °C.

Figure 4. Temperature (°C) distribution in the billet after one pass upsetting

4. Summary
In this paper, the equivalent strain, effective stress, and temperature field of billet during repeated upsetting were analyzed by using finite element simulation technology. The main conclusions are as follows:

(1) The average equivalent strain in the billet increases with the increase of upsetting pass, and the strain in the upper middle part is the smallest, while that in the bottom middle part is the largest.

(2) The high stress zone in the billet is the edge contact area between the billet and the punch.

(3) Temperature in the billet presents a gradient distribution, which gradually decreases from the punch contact area to the edge, and the lowest temperature distributes at the corner.
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6. References
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