Materials Science and Engineering A 421 (2006) 226–237

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Proposal and use of a void model for the simulation of shearing

Kazutake Komori *

Department of Computer Mechanical System Engineering, Daido Institute of Technology, 10–3 Takiharu-town, Minami-ward, Nagoya-city, Aichi-prefecture 457–8530, Japan

Received 9 December 2005; accepted 20 January 2006

Abstract

In our previous paper [Acta Mater. 47(10) (1999) 3069–3077], a new model of void coalescence, which was derived with reference to Thomason's model of void coalescence based on internal necking, was proposed and proved to be effective in the analysis of multipass drawing. In this paper, the simulation of shearing is performed using our proposed model. First, the two void shapes and two void configurations in our previous study are unified into one void shape and one void configuration to improve the proposed model. Then the analysis and the experiment of shearing are performed, and the validity of our proposed model is clarified by comparing the analytical results with the experimental results.

Keywords: Fracture; Ductility; Micromechanical modeling; Forming processes; Void

1. Introduction

Ductile fracture [1,2], which occurs when a material is subjected to large plastic deformation, is a troublesome problem in metal-forming processes. Hence, macroscopically, it is important to determine the fracture criteria of materials. However, no fracture criteria have been found which are applicable to all metal-forming processes [3–5].

We have developed a new computer program based on a conventional computer program of the finite-element method. Using this computer program, the behavior of crack propagation after ductile fracture can be analyzed. The simulation of inner fracture defects in drawing [6,7] and the simulation of shearing [8,9] has been performed, and the validity of the computer program has been demonstrated. In those simulations, the fracture criterion is that the material fractures when the void volume fraction of the material reaches a certain value. However, microscopically, the fracture criterion does not necessarily have a definite physical meaning.

Microscopically, ductile fracture occurs through the nucleation, growth and coalescence of voids. Hence, much analytical and experimental research on the nucleation, growth and coalescence of voids has been performed. The analytical research using the finite-element method, in which a unit cell model is usually used, has been extensively performed in the last 30 years [10–15]. The merit of the finite-element method is the high accuracy of the calculated results, while its disadvantage is that large amounts of computation time and memory capacity are required. Hence it is almost impossible to estimate whether the material fractures or not by the finite-element method in which a unit cell model is used in the simulation of metal-forming processes.

The analytical research on techniques other than the finite-element method, in other words, analytical research using the elementary method or the upper bound method, has also been performed [16–29]. The merit of these methods is that no computation time or memory capacity is required for the analysis, while their disadvantage is that calculated results are only obtainable under limited boundary conditions. Thomason proposed a model of void coalescence based on internal necking of the intervoid matrix ligaments [18,23–25]. The model was derived from the upper bound method, in which the material is assumed to fracture when the energy required to coalesce voids by internal necking is less than the energy required to deform the material homogeneously. Using the model, the relationship between the strain to fracture and the void volume fraction of the material is calculated. The relationship agrees well with the relationship obtained by Edelson and Baldwin [30] from the uniaxial tensile test of copper alloys. Since the model of void coalescence has definite physical meaning, the model is useful. Therefore

* Tel.: +81 52 612 6111; fax: +81 52 612 5623.
E-mail address: komori@daido-it.ac.jp.

0921-5093/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2006.01.056

the model of void coalescence is derived from the upper bound method in much research [21,22,26–29].

In the Thomason model [18], the following assumptions are made.

- The shape of a void is a rectangle.
- The longitudinal direction of a void coincides with the direction of maximum principal stress.

In other words, the direction of principal strain is not assumed to change during plastic deformation in the model. However, the direction of principal strain changes during plastic deformation in metal-forming processes. Hence, the model cannot be utilized in the analysis of metal-forming processes.

In our previous paper [26], we proposed a new model, based on the Thomason model, which can be utilized in the analysis of metal-forming processes. In our model, the following assumptions are made.

- The shape of a void is a parallelogram.
- The longitudinal direction of a void does not coincide with the direction of maximum principal stress.

In other words, the direction of principal strain is assumed to change during plastic deformation in our model. Our model is incorporated into a computer program of the finite-element method, which we have already developed to analyze the behavior of crack propagation after ductile fracture. The simulation of inner fracture defects in drawing is performed, and the validity of our model is demonstrated.

In this study, the simulation of shearing is performed using our proposed model. First, the two void shapes and two void configurations in our previous paper [26] are unified into one void shape and one void configuration to improve the proposed model. Then the analysis and the experiment of shearing are performed, and the validity of our proposed model is clarified by comparing the analytical results with the experimental results.

2. Method of analysis

2.1. Outline of whole analysis

Fig. 1 shows the flow chart of the analysis. First, the displacement of the tool at the mth step is assumed. Whether or not the material fractures at the mth step is determined by means of our proposed microscopic model. When the material fractures at the mth step, the displacement of the tool at the mth is modified such that only one element fractures at the mth step. Next, one node is separated into two nodes so that the element may fracture. Finally, the displacement of the tool at the $(m+1)$th step is assumed. When the material does not fracture at the mth step, the displacement of the tool at the $(m+1)$th step is assumed. When the material has not fractured before, remeshing is performed in each step. The analysis is performed until the material is divided into two materials.

2.2. Outline of macroscopic analysis

The analysis of the displacement of the material is performed using the conventional axisymmetric rigid-plastic finite-element method [31]. The yield function Φ proposed by Gurson [32] is

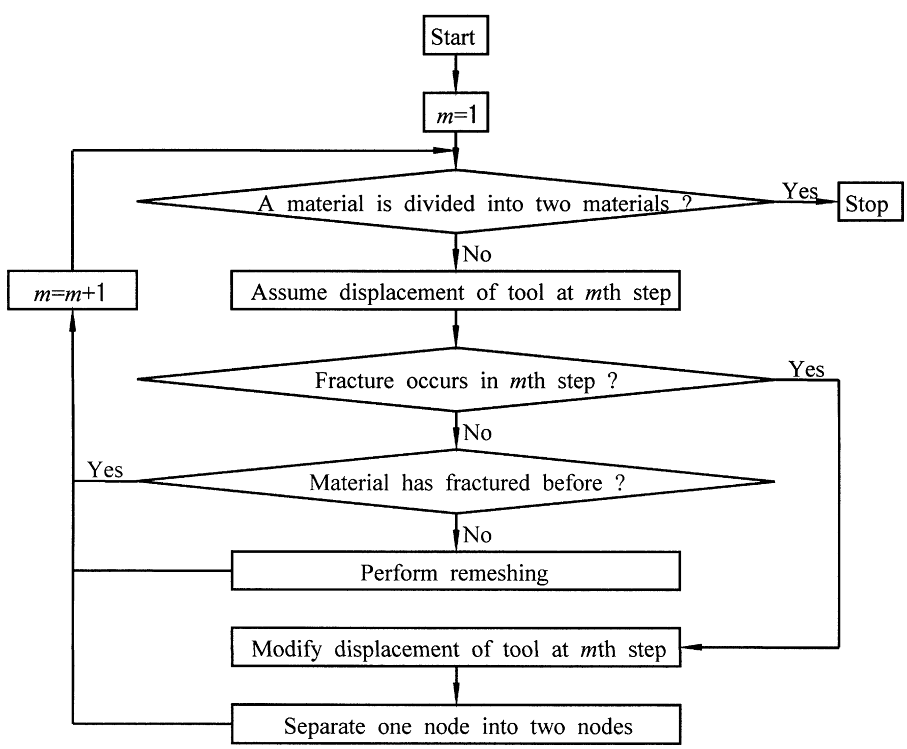

Fig. 1. Flow chart of analysis.