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Coefficient of friction at interface of lubricated upsetting process

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ABSTRACT

In the lubricated upsetting process, it is well known that the coefficient of friction over the contact surface between the tool and the workpiece is distributed nonuniformly and changes with the reduction in height and the position at the interface. In order to increase the reliability of the numerical simulation of cold forging processes, more precise input data of the coefficient of friction at the tool–workpiece interface have become necessary. In this study, in order to predict the coefficient of friction at the interface lubricated cylinder upset tests are carried out using a specimen of commercially pure aluminum and a liquid lubricant. The displacements of the points located at the interface are measured. The normal stress and the tangential stress acting on the interface are calculated by the finite element method, using the measured displacement. Then, the coefficients of friction are estimated using Amonton–Couloumb's friction law. The coefficients of friction depend on the reduction in height and the position at the interface.

1. Introduction

Recent societal circumstances have led to new innovations for metal forming process, namely those in harmony with the environment. In the field of cold forging, they include the development of new lubricants to replace phosphates and soap lubricants. Biodegradable lubricants have been developed as environmentally friendly lubricants for cold metal forming processes [1].

It is well known that the liquid lubricant is entrapped at the interface between the tool and the workpiece in an upsetting process and the entrapped lubricant affects on the coefficient of friction at the interface [2]. The authors [3] attempted to measure the lubricant behavior between the tool and the workpiece of the end surface in upsetting of the cylinder accompanied by a reduction in height, using a newly developed upsetting experimental apparatus which consisted of a transparent die made of quartz, a microscope with a CCD camera, a video system and an image processor. They observed directly that at the beginning of upsetting, the lubricant was trapped between the tool and the workpiece, and then the asperities generated with surface roughening during plastic bulk deformation were flattened by the flat tool. They found that the fraction of real contact depended on the reduction in height and the point in the surface at the interface, and at the same time the coefficient of friction depended on the reduction in height and the point in the surface at the interface.

In the numerical simulation using FEM in metal forming, the friction models were considered [4,5]. For improved reliability of the numerical simulation of cold forging processes, more precise input data of the coefficient of friction at the tool–workpiece interface have become necessary. If the highly precise solution in the numerical simulation using FEM is desired, the distribution of the coefficient of friction at the interface between tool and workpiece in upsetting process must be given.

Either a constant Amonton–Coulomb coefficient [6] or a constant friction factor [7] is practically applicable to most forming processes. However, for unsteady forming processes such as forging, the use of a constant value of coefficient of friction is not usually possible.

A friction model which can be used in the numerical simulation of cold forging processes with high accuracy must be derived. In particular, it is necessary to investigate quantitatively the dependence of the coefficient of friction on the reduction in height and the position at the interface in order to obtain the distribution of the coefficient of friction using the new friction model [8].

In this paper, for the purpose of developing the new friction model in cold forging processes, the displacements of points at the interface in the lubricated aluminum cylinder upset tool are measured at several levels of the reduction in height after upsetting. Then, the normal stress and the tangential stress at the point accompanied with reduction in height in upsetting of cylinder are calculated by the elastic-plastic finite element method, using the measurements by assuming the Amonton–Coulomb's friction law. The dependence of the coefficient of friction on the reduction in height and the point at the interface are measured. The new mixed

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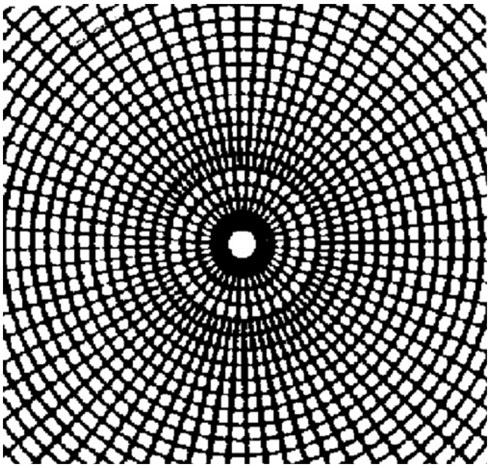

Fig. 1. Master of circular lattice pattern.

lubrication model at the interface between tool and workpiece in upsetting process with lubricants is proposed.

2. Experimental procedure

The workpiece material used is commercially available pure A1050H aluminum. Cylindrical specimens with a diameter of 16 mm and a height of 4 mm are machined from a cold drawn rod and are annealed for 1 h at 350 °C. The top and bottom surfaces of the specimens are polished to a smooth surface of Ra 0.2 μm. Then, a scribed pattern is printed on the top end surface of the cylindrical specimen by a photograph image method using a film with a circular lattice as shown in Fig. 1. The interval of the circular patterns is 1 mm and the diameters of the circular patterns range from 2 mm to 16 mm. The photograph of the specimen is shown in Fig. 2.

The upsetting experiments between flat tools are carried out at a constant speed of approximately 0.6 mm/min at up to four levels of reduction in height ranging from 10 to 40%. The surface roughness of the tools is measured. Paraffinic oils having three levels of viscosity (P400: 1460 cSt, P30: 80 cSt, P8: 24 cSt at 20 °C) are used as a lubricant. The experiments are carried out at room temperature (20 °C). After carrying out the upsetting tests at up to four levels of reduction in height of 10, 20, 30 and 40%, the displacements of the lattice points of eight circular patterns at each reduction in height is derived by the elongation of each element.

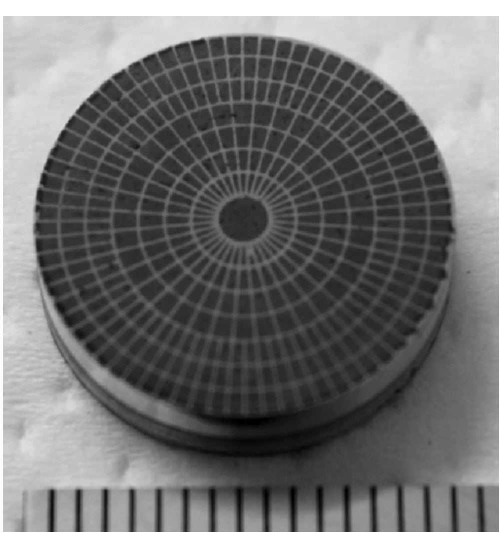

Fig. 2. Photograph of the specimen.

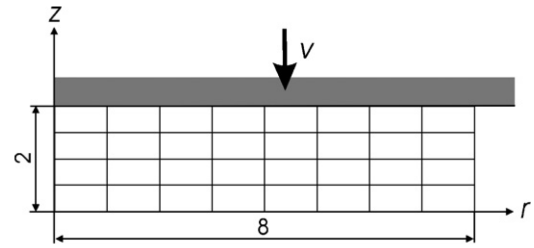

Fig. 3. Geometry and finite element discretization of specimen.

3. Modeling for calculation

The ABAQUS/Standard version 6.2 is used for calculating the coefficient of friction at the lattice points accompanying the reduction in height in the upsetting process. The cylindrical specimen with a diameter of 16 mm and a height of 4 mm is used and the geometry and the finite element discretization of the specimen are shown in Fig. 3. In the quarter of the specimen, the height is 2 mm and the radius is 8 mm.

The model workpiece is compressed between the two flat parallel tools. The computations are carried out under axisymmetrical conditions. The stress–strain curve of the workpiece is measured by the repetitive compression testing under lubricated conditions [9]. The relationship between the stress and the strain obtained by the experiment is shown in Fig. 4. The stress–strain curve used for calculation is given by

$$\sigma = 157\varepsilon^{0.27} \tag{1}$$

where σ is the flow stress and ε is the true strain.

At the first stage of calculation, for the boundary conditions the tool is assumed to move at a constant compression speed and Amonton–Couloumb's friction law at the tool–workpiece interface is used as the frictional boundary condition. The frictional shear stress τ_f is expressed using a coefficient of friction μ as

$$\tau_f = \mu p \tag{2}$$

where p is the normal pressure. The values of the coefficient of friction are 0.1, 0.2 and 0.3.

At the second stage of calculation, for the boundary conditions the tool is assumed to move at a constant compression speed and the displacements in the horizontal direction at the nodal points at the interface accompanied with the reduction in height are given by experimental data. The normal stress and the tangential stress at the nodal points are calculated, and the coefficients of friction

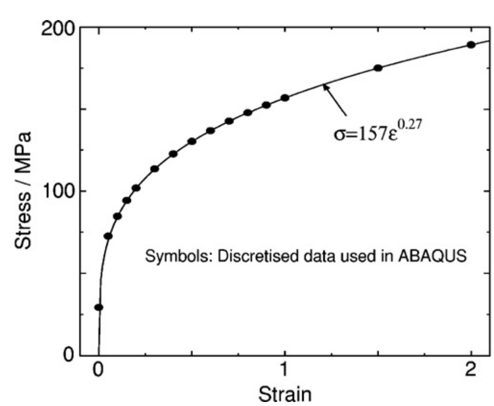

Fig. 4. Constitutive equation used in the analysis.