CHAPTER - 1

INTRODUCTION

1.1 METAL FORMING

Metal forming is a process by which material is plastically deformed by application of mechanical forces through dies or tools to obtain a useful component. Metal forming process is influenced by the input variables such as work piece material, dies, the conditions at the die-work piece interface, the mechanics of shape change in the work zone, and the characteristics of the process equipment (Fig. 1.1). Thus in designing and developing a metal forming process, key technical problem areas may be listed as follows:

- **Work piece material** - shape and size, chemical composition and microstructure, flow properties under processing conditions.
- **Forming dies or tools** - geometry, surface roughness, material and hardness, surface coating, temperature, stiffness and accuracy of dimensions.
- **Interface conditions** - surface finish, lubrication, friction, heat transfer characteristics.
- **Work zone** - mechanics of plastic deformation, material flow, stresses, velocities, temperatures.
Fig. 1.1 Variables of bulk forming process
The understanding of these process variables will allow better prediction of the characteristics of the formed products i.e. geometry and tolerances, surface finish, microstructure and mechanical properties (Altan 1996).

1.2 ROLE OF FRICTION

Of all these variables, friction plays an important role in metal flow characteristics. In metal forming the flow of metal is caused by the pressure transmitted from the dies to the deforming workpiece. Due to the relative velocity between the deforming workpiece and the die, friction develops at the die - material interface. This friction greatly influences metal flow, formation of surface and internal defects, stresses acting on the dies, die wear, surface finish, load and energy requirements. Thus, the selection and use of an appropriate lubricant will have considerable influence on the quality and economics of forgings. It is not economically practicable to test a large number of lubricants in production because the performance of lubricants can not be predicted quantitatively and production loss may be high. Therefore, it is desirable to test the lubricant in a laboratory condition under actual production conditions (Isogawa, Kimura, Tozawa 1992). In order to evaluate the performance of various lubricants, it is necessary to express the interface friction quantitatively, in terms of coefficient of friction ‘μ’ or shear friction factor ‘m’. In the past, a number of testing methods have been proposed and developed by many researchers to evaluate the frictional conditions in bulk metal deformation processes.
1.3 METHODS AND MEASUREMENT OF FRICTION

1.3.1 Friction measurement by feeler pins

In early investigations, the feeler pins were inserted through the tool to the tool-work interface and the frictional values were calculated from the measured interface loads. Schroeder and Webster (1949), Frich and Thomsen (1954), van Rooyan and Backofen (1960), Pearsall and Backofen (1963), Nagamatsu, Muroto and Jimma (1971), Al-Schey (1983) and Lim and Lenard (1984) applied the pin technique to measure the frictional conditions at the tool-work piece interface. The advantages of the pin techniques are

(i) the stresses can be directly measured
(ii) it provides clear insight into lubrication and friction in metal forming operations.

The limitations of the pin techniques are

(i) this technique is expensive
(ii) this method can not be applied outside of the laboratory.

1.3.2 Friction measurement by ring compression test

The ring compression test is one of the simplest tests to evaluate the frictional condition at the die-material interface. It requires a simple geometry ring specimen. The details regarding the dimensions of the specimen, test procedure and limitations of the ring compression test are given in section 2.5. The frictional condition can be evaluated by this test independent of the load and flow stress of the work material. However, in ring compression test, the amount of normal pressure, amount of strain and new surface generated are
relatively small compared to the actual conditions present in closed die cold forging. Hence, a better friction test to reflect the severe deformation condition is required.

1.3.3 Friction measurement by double cup extrusion test

A Double Cup Extrusion (DCE) test is a friction test to evaluate frictional conditions under severe plastic deformation which was proposed by Altan and his team (1992). DCE test consists of a combined forward and backward extrusion in which two cups are generated by the simultaneous action of the punches inside a cylindrical container. The ratio between backward cup extrusion height \( h_1 \) and forward extrusion cup height \( h_2 \) is controlled by frictional conditions at the container - work interface. The details of this test are given in section 2.10. The advantages of this test are

(i) A simple method to evaluate friction.
(ii) Load for deformation need not be measured.
(iii) The test reflects the actual frictional condition existing in cold forging processes.
(iv) The value of the friction factor can be determined continuously during the forming process.

1.4 NEED FOR THE PRESENT STUDY

Ring test is a standard test to evaluate friction in bulk metal forming. The frictional values found out from ring tests varies and the amount of variation depends on the type of lubricants, ram speed and amount of deformation (Male 1964). In cold forging especially closed die forging and
precision die forging, the interface pressure and severity of deformation are high. The amount of deformation, interface pressure and new surface generated in the ring test are comparatively smaller than the actual cold forging conditions. Such high interface pressure and severity of deformation in industrial cold forging can not be realistically reproduced in the ring test (Kropp 1988).

Eventhough the combined forward rod and backward cup extrusion test (Sanchez et al 1985) develop high interface pressure and large surface expansion, the experiments conducted by Popilek (1991) on this test showed that the test is not very sensitive to small changes in the actual lubrication conditions. Bucket test developed by Shen et al (1992) needs an accurate measurement of bottom thickness of the specimen and load. It is difficult to measure the bottom thickness.

Therefore, an alternate test method to measure the frictional conditions existing in cold forging condition is needed.

Buschhausen et al (1992) simulated double cup extrusion (DCE) test to investigate the friction conditions in cold forging where new surface generated and interfacial pressure are large. They demonstrated the usefulness of DCE test to evaluate friction. The test conditions for FEM analysis were designed to correspond with the experiments conducted by Geiger (1976) on the extrusion process combining both forward and backward extrusions. Their theoretical results were validated with the experimental values of Geiger (1976). In their study, the influence of various reduction ratios and billet geometries has been examined and the calibration curves were drawn. The
calibration curves were proved to be useful one to measure friction because even small variation in frictional conditions were reflected in the curves.

Ghobrial et al (1993) conducted an analysis on double cup extrusion test using FEM. The effect of friction factors and the effect of punch diameters on the cup height ratio were studied. Three different kinds of solid film lubricant namely zinc stearate, alumina coating and alkali soap and aluminate coating were evaluated. The metal flow behaviour and punch load for the DCE test were also studied.

In the earlier studies, punch geometries for the DCE test were selected to suit the experiments of Geiger (1976) or to suit the forward extrusion process. A systematic study on the selection of punch geometry for the DCE test is needed to standardize the test. Also the influence of the punch geometry on the metal flow characteristics in double cup extrusion needs further investigation. As discussed in Ghobrial et al (1993), the increment in strain at the corner of the upper punch area is more than the increase at the corresponding areas close to the lower punch which needs a more detailed study. The double cup extrusion test is not yet standardized and it is in the developing stage. Hence further investigation on double cup extrusion test is attempted in this study, on the above aspects.

1.5 USEFULNESS OF FEM

Finite Element Method (FEM) simulation is widely applied in research as well as in industrial practice. In many process development and design situations FEM simulations have replaced full scale process trials, thereby reducing process time and cost compared to conventional experimental
iterative methods. FEM simulations of metal forming give information on metal flow, stresses, strains, strain rates and temperature distributions within the deforming metal, stresses exerted on tools and potential defects and failures. In some cases, it is even possible to predict product microstructure and properties as well as elastic recovery and residual stresses. A geometrically complex product requires 3D simulations because the metal flow is of three-dimensional in nature. The application for 3D problems is still not widely used in practice because it is not always cost effective and requires considerable engineering and computation time. With appropriate interpretation of 2D results, it is possible to obtain very useful information for 3D deformation processes as well (Knoer, Lee and Altan 1992). Simulation of 2D axisymmetric and plain strain is truly state of the art (Altan 1996). The accuracy of FEM simulation results greatly depends upon the input data. In order to improve the exactness of computer simulation results, more precise input data on friction at the die-material interface have become necessary.

1.6 SCOPE OF PRESENT STUDY

In the present study, finite element technique was used to analyse the double cup extrusion test. The basic parameters that affect the metal flow in DCE test are (i) punch geometry (ii) specimen geometry and (iii) flow stress of the metal. The metal flow characteristics on the double cup extrusion test were examined by varying the basic parameters. The effects of punch geometry on the extrusion cup heights, the stress and strain distribution around the nose radius of the punch and the normal pressure distribution on the container wall were studied. The punch geometries were selected based on minimum load required and the uniform distribution of stress and strain distribution around the nose radius. In order to evaluate the various lubricants, a set of calibration
curves for various frictional values has to be drawn. The calibration curves were drawn using FEM for the friction factors ranging from 0.01 to 0.3.

A suitable experimental set up was designed and fabricated to conduct double cup extrusion test. Experiments were conducted on annealed pure (commercial) aluminium work material. Three different types of lubricants namely teflon, soap, and castor oil were evaluated by the DCE tests. To determine whether the testing method influences the friction factor, the same lubricants were also evaluated by ring tests and the frictional values found out from DCE and ring tests were compared.

Finite element simulations were performed with the work piece diameter of 20mm and height 20mm (i.e. height to diameter ratio 1.0). The flow properties of the billet material were selected from the experiments conducted on the specimen material. To study further on the flow behaviour in the DCE test, FEM simulations were performed for the selected three strain hardening coefficients 0.001, 0.20 and 0.45.

A theoretical prediction has to be validated by experiments. In order to validate the applicability of these tests, two sets of FEM simulations were performed on closed die forging processes one using the value of friction factor found by DCE test and the ring test separately.

1.7 SIGNIFICANCE OF THE STUDY

As already stated DCE test is still to be standardised. A detailed study on DCE test is significant due to the following reasons.
(i) A systematic study is made to determine the effects of punch geometries on metal flow in DCE test.

(ii) The best punch geometry is selected for a higher cup height ratio i.e. higher sensitiveness even for a small changes in friction conditions.

(iii) The punch geometry is designed to get a lower punch load.

(iv) The frictional values found out from DCE and ring compression test were compared.

(v) The applicability of the frictional values found by the DCE test on the forging process was analysed.

Hence, it is evident that the present study has an important engineering relevance.

1.8 OBJECTIVES

The present study on the evaluation of friction using double cup extrusion test and ring compression test is performed with the following objectives:

(i) To study the effect of punch geometry such as punch diameter, nose radius, conical angle and land on the metal flow behavior.

(ii) To compare the friction factors evaluated by ring compression test with DCE test.

(iii) To study the effect of strain hardening index of material on metal flow characteristics in DCE test.
(iv) To compare the theoretical prediction of metal flow using the friction factor found from the ring compression and DCE tests with the experimental results.

(v) To develop a reliable test method to reflect the actual condition present in the cold forging i.e. high surface pressure, severe deformation, substantial enlargement etc.