ABSTRACT

In metal forming, friction greatly influences the metal flow, formation of surface and internal defects, stresses acting on the dies, die wear, surface finish, load and energy requirements. Because of these effects, friction is considered as a major variable in metal working operations and must be controlled to optimize process procedures for economically producing good quality product with desired internal structure.

Of the many laboratory tests used to measure the frictional conditions in bulk forming, the ring compression test is the most commonly used. However, frictional values measured with the ring compression are not applicable to precision forging and closed die forging where the interface pressure, new surface generation and deformation conditions are high. The simple geometry and small contact area at the ring-platen interface, make the ring test not reliable as a general method for evaluating the lubrication effects. Kroop, Udagawa and Altan (1988) indicated that the high interface pressure and severity of deformation in industrial forging operation cannot be reproduced realistically in the ring test.

Nowadays, several commercial FEM codes are available for the simulation of bulk forming processes. For accurate and efficient use of FEM simulation, it is not only necessary to have a reliable FE solver but also appropriate input data. The accuracy of the FEM prediction depends upon precise input of frictional value. Therefore a reliable and accurate testing
method is needed to find the actual frictional conditions existing between the material and the tool interface.

A new technique namely Double Cup Extrusion (DCE) test is emerging as an alternate test for evaluation of friction under severe plastic deformation condition. 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 needed.

In the present study, finite element technique was used to analyze ring and double cup extrusion tests. The primary objectives of this study are i) optimizing the parameters of DCE test punch and ii) comparing the accuracy of ring compression and DCE tests in the evaluation of friction. The punch parameters considered for the DCE test are punch diameter (12 and 14mm), punch nose radius (1, 2, 4 and 7mm) conical angle (160°, 170° and 180°) and land width (0.2, 4 mm straight and 4mm inclined at 4°). The effects of punch geometry on the metal flow, load on the punch, the stress and strain distribution in the specimen and the radial pressure on the container were studied.

The cup height ratio for the 12mm diameter punch was normally higher than that for the 14mm diameter punch whereas individual cup heights viz. \( h_1 \) and \( h_2 \) were more in the case of 14mm diameter punch for a given % reduction in height. This is due to large surface enlargement in the 14 mm diameter punch. The punch pressure for the 14 mm diameter punch was lower than that for 12 mm diameter. The radial pressure distributed on the container wall was higher for 14 mm diameter punch. Though 12 mm diameter punch resulted in a higher cup height ratio, the other favourable responses such as
individual cup heights, higher radial pressure and lower punch pressure were observed in 14 mm diameter punch. Therefore a 14 mm punch diameter was selected for the present study.

From the simulated results of DCE test, it was found that the cup height ratio increases as the nose radius increases. Fluctuation in the cup height ratio, smaller cup height and lesser surface enlargement in the initial stages were found for 4 and 7 mm punch nose radii. Therefore, 4 and 7 mm nose radii are not suitable for DCE test. The difference in cup height ratio for the 1 and 2 mm radii is not significant in practical range of low frictional conditions (ie. m = 0.01 - 0.10) whereas in 1mm radius the individual cup heights were comparatively higher in the initial stages. Therefore, 1 mm radius was preferred for the study.

The results of DCE test using conical angles namely 160°, 170° and 180° with 1mm nose radius indicated that higher cup height ratio was obtained for 160° compared to 170° and 180°. The load required for 160° conical punch is lower than the load required for 170° and 180°. Therefore 160° conical punch with 1mm nose radius was preferred.

On studying the effect of land width, it was found that there was no difference in cup height ratio for land variation. But the load required was lower for the 0.2 mm land than 4 mm land. The load required for the 4mm straight land and inclined land were almost the same. Hence a 0.2 mm land was preferred. Based on the above studies, a 14 mm diameter punch having 1mm nose radius, 160° conical angle and 0.2 mm land was selected for DCE test simulations to draw theoretical calibration curves. The predicted backward extrusion cup height (h₁) and forward extrusion cup height (h₂) were measured
from the plots of the simulated results. The theoretical curves ie. cup height ratio \( h_1 / h_2 \) vs. % reduction in height were drawn for friction factors 0.02, 0.03, 0.05, 0.10, 0.20 and 0.30.

Samples for experiments were machined from an annealed bar of commercial pure aluminium. The stress and strain values obtained from compression test were used as input of material data of aluminium model in FEM simulations. Three lubricants namely teflon, soap and castor oil were evaluated by ring compression test and the friction factor ‘m’ found out as 0.16, 0.25 and 0.30 respectively. The ‘m’ values found out from the DCE test for teflon, soap and castor oil were 0.05, 0.12 and 0.14 respectively. The friction factor ‘m’ for these lubricants determined both with ring and DCE tests methods were different values. It may be observed that ‘m’ values found out by DCE tests were lower than the ‘m’ values found out by ring tests. Hence it was concluded that the testing method influences the predicted value of friction factor ‘m’.

In order to compare the applicability of these ‘m’ values, validation experiments were conducted using closed die forging process. Steel dies for forging a hub component were made. Using these dies, aluminium specimens were forged with the selected lubricants to form the components. The change in shape of the specimens was measured at three stroke lengths. These results were compared with the simulated results using the ‘m’ values found out from the ring and DCE tests. It was found that the dimensions measured in the experiments were in close agreement with the simulated results using the DCE ‘m’ values. The load for cold forging process was measured. The FEM results were also in good agreement with experimental values.
In summary, the systematic investigation to optimize the geometry of DCE test punch indicated that a punch with 14 mm diameter, 1 mm nose radius, 160° conical angle and 0.2 mm land width could be standardized. Punch with these standardized features proved its sensitivity by resulting in a significant change in cup height ratio even for a small changes in friction. The ‘m’ values for teflon, soap and castor oil found out from ring compression test are 0.16, 0.25 and 0.30, whereas the values obtained from DCE test are 0.05, 0.12 and 0.14 respectively. On validation, the predictions of material flow using ‘m’ values of DCE test are found to be closer to the experimental values.