ABSTRACT

Interface friction between the tooling setup and the billet that is worked upon plays a crucial role in any metal forming operation in determining the metal flow, formation of new surface, surface finish, external and internal defects, stresses acting in the tooling setup, tool and die wear, load and energy requirements. Hence it is important to quantify this interface friction and keep it within limits, so that the required quality level is achieved economically in the finished product and to ensure the stress level in the tooling setup always is in the safe working range.

Of the tribo-tests used to measure the interface friction in bulk forming, ring compression test is the most commonly used one, but double cup extrusion test is one of the most accurate tests. The friction values measured using ring compression test are not applicable to closed die forming and precision forming processes, since the values obtained are approximate. The tests used for simulating open forming processes do not have high interface pressure and thus severity of the deformation cannot be reproduced. In case of the tests that represent closed forming processes the test setups would be too elaborate and complex. The punches are slender and prone for breakage. Getting out the test specimen that has stuck in the container is extremely difficult. Hence, a new tribo-test has been devised to overcome the disadvantages suffered by the existing tribo-tests.

At present several powerful computer programs that use FEM are available for the simulation of the bulk metal working processes. For accurate and efficient use of the FEM simulation, it is a prerequisite to have a reliable FE solver and appropriate input data. To predict the behaviour of the different variables that exist during forming processes, it is
necessary to accurately measure the interface friction that arises between the tooling setup and the billet interface.

A new tribo-test namely Backward Spike and Forward Disc Forming (BSFDF) tribo-test has been devised and tested for its viability to quantify the interface friction. This test simulates closed forming processes under severe plastic deforming condition.

In the present work, finite element technique is employed to analyze the BSFDF test. DEFORM-2D is the software used. The primary objectives of this study are i) to prove the suitability and viability of the test to quantify the interface friction and ii) to find the optimum dimensions for the test setup that generate highly sensitive calibration curves to measure the interface friction.

The BSFDF test setup consists of a hollow punch forcing the solid cylindrical punch inside a container, which is fitted to a flat rigid base plate. The container has a countersunk chamber on the base plate side. During the movement of the punch, a split flow of the material is taking place - a spike is extruded along the hole in the punch and a tapered disc is formed in the countersunk chamber of the container. Change in disc diameter is defined as the difference between the disc diameter at the measured step and the billet diameter. The ratio of the spike height to the change in disc diameter is a measure of interface friction.

The parameters of the test setup considered for a detailed analysis are the dimensions of the billet, the hollow punch dimensions, and the container dimensions. The effects of the above dimensions on the material flow, load on the punch, strain and stress distribution, radial pressure on the container have been studied. The spike height is lower when the punch-hole diameter is less whereas the disc diameter is more. But when the punch-hole diameter
increases, the spike height increases and the disc diameter decreases. An optimum value of the punch-hole diameter is identified to have a better ratio of spike height to change in disc diameter.

From the simulated results of the BSFDF test, it is found that the spike height and the change in disc diameter are high when the punch hole diameter is 12 mm from the apparently available values of 10 mm, 12 mm, 14 mm and 16 mm. The optimum value of the ratio of height by diameter of the billet is 1.0 from the choices of 0.75, 1.0 1.25 and 1.5. The countersunk chamber taper angle is assigned a value of $14.93^\circ$ which is optimum from the choices of $11.1^\circ$, $13.13^\circ$, $14.93^\circ$, $17.1^\circ$ and $20^\circ$. For the punch tip radius, 2 mm was found more suitable and for the disc root radius it was 1 mm. The spike height and the change in disc diameter are obtained in the simulations for known % reduction in the original height reduction of the billet and the ratio is plotted to form the theoretical calibration curves. Calibration curves are drawn for the shear friction factor ‘$m$’ values of 0.01, 0.03, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.4.

Samples of aluminium alloy 6063 bar were obtained from an annealed bar of 20 mm diameter. The stress strain values obtained from a simple upsetting test were used as input flow stress for the material data in the simulation. Four lubricants, Teflon tape, zinc stearate, mineral oil and molybdenum disulphide were used in the experimentation. The shear friction factor values found from the BSFDF test are 0.03, 0.2, 0.12, 0.14 respectively for teflon tape, zinc stearate, mineral oil and molybdenum disulphide.

In order to ensure the repeatability of the BSFDF test, four other materials namely copper, brass (70-30), aluminium alloy 1100 and pure lead were taken up for experiments.
The lubricants used were Teflon tape, molybdenum disulphide, mineral oil, and a mixture of soap with mineral oil. The results were tabulated and compared with the values available in the literature. It is found that the results closely agree with the results already available in the literature. In order to compare the applicability of these shear friction factor values, validation experiments were conducted using closed die forming process. Steel dies for forming a bush which is used in a passenger coach have been made. Using the setup, aluminium specimens were formed with the selected lubricants to form the finished components. The change in the shape of the specimens was measured at two stroke lengths. These results were compared with the simulated results using the shear friction factor values found out from the BSFDF test. It is found that the values obtained from the experiments are in good agreement with the simulation results using the BSFDF test.

In summary, a detailed systematic study is carried out to find the suitability of the BSFDF test to measure the interface friction that exists during the forming process. The ratio of the spike height to change in disc diameter is a measure of this interface friction. The dimensions of the setup have been optimized. Experimental validation is made using different materials for forming and using different lubricants. A component used in industry is then simulated using the values obtained from the BSFDF test. The simulation is then compared with the data taken from the actual forming process with which the component is made. The comparison indicates that the simulation agrees closely with the results obtained from the actual process. Hence, it is concluded that the BSFDF tribo-test is a suitable test to quantify the interface friction that arises during the forming processes.