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Quantifying Interface Friction Using Backward Spike and Forward Disc Forming Test

[1]R. Velu and [2]Moses Raja Cecil
[1]Department of Mechanical, Dr. M.G.R. University, E.V.R. Salai, Chennai, Tami Nadu, India
[2]Design and Development Division, Integral Coach Factory Chennai, Tamil Nadu, India

Abstract: Interface friction plays an important role in cold forming and forging. Since, this shear force if not taken care of would cause many defects and problems, it is essential to measure and control this entity. Using backward spike and forward disc forming test, this interface friction is quantified. A cylindrical billet is extruded to form a backward spike on one side and upset to form a forward disc on the other. Aluminium alloy 6063 is used as the specimen billet material. Simulations are carried out for various combinations of height/diameter of the specimen billet and for different spike diameters. The ratio of the height of the spike to the disc diameter is the measure of the interface friction. This ratio is then plotted in a graph to form the calibration curves using which the interface friction present during the forming process is quantified.

Key words: Interface friction, disc forming, spike extrusion, calibration curves, lubricants

INTRODUCTION

Cold forming is a rapid, effective and efficient bulk forming process employed to produce a part with less material wastage. Parts with intricate details can be manufactured in a short time using cold forming process than any other process. The effectiveness of this process has enabled it to retain the edge over other processes. The development in various fields would not have been possible without the advancement in forming.

The quality of the formed part depends upon many vital characteristics like the ability of the bulk metal to flow and fill up of the die. During any forming process, there exists relative movement between the tooling setup and the bulk metal being worked upon; hence, there arises interface friction in the common boundary between them. This interface friction if not controlled can cause many serious faults like inadequate die filling, cracks and discontinuities, subsurface defects and porous surfaces in the formed part, premature wear and tear of the tool and die setup, increased energy requirements, stalling of the press/forge (Gopal, 2001). Therefore, if a fit part has to be made, this interface friction has to be controlled and kept within safe limits. The first step in controlling this interface friction is to quantify the same and then accordingly select a suitable lubricant and apply the lubricant during the forming process.

In bulk metal forming, the lubricating characteristic of a lubricant affects the interface friction arising during the process. It is in general, expressed in two terms, shear friction factor, m and co-efficient of friction, μ.

In theory of metal forming, frictional shear stress, τ, acting tangentially to the surface is expressed using the equation (Schey, 1970):

$$\tau = \mu\sigma_n \quad (1)$$

Where:

σ_n = The normal stress or pressure that acts perpendicular to the surface
μ = Constant co-efficient of friction

This constant co-efficient of friction theory could not truly represent the bulk forming operation (DePierrie and Gurney, 1974). Hence, constant shear friction factor, m is used for analysis:

$$\tau = \frac{m\sigma_0}{\sqrt{3}} \quad (2)$$

where, σ_0 is the flow stress of the billet material. The flow stress again depends upon strain, strain rate and temperature. The value of m varies from 0 to 1 where, when m = 0 represents frictionless interface and m = 1 represents sticking friction. Studies (Altan *et al*., 1983) indicate that Eq. 2 represents the frictional shear stress to a greater and closer extent in bulk metal processing than Eq. 1. Usage of the shear friction factor offers a distinct advantage in evaluating interface friction and load calculation. Hence, to find this shear friction factor many tribo tests have been conducted.

During mass manufacturing in a production unit it is impractical to quantify the interfacial friction since this

Corresponding Author: R. Velu, Department of Mechanical, Dr. M.G.R. University, E.V.R. Salai, Chennai, Tami Nadu, India

would affect the regular production (Valberg, 2010). Tribological tests like Ring Compression test, Simple Upsetting test, Spike Forging test (Cecil, 2003) Double Cup Extrusion (DCE) (Gopal, 2001) test, Compression and Twist test (Hansen and Bay, 1986) have been conducted in laboratory conditions to measure and quantify the interface friction. These tests differ in their aspects of the complexity of the setup and their aptness to simulate the exact production conditions. The simplest of the tests is ring compression test (Abdul and Alexander, 1981) and a comparatively complex test is Compression and Twist test. It has been tried to measure the interfacial friction of magnesium alloys using Forward Rod Backward Cup Extrusion (FRBCE) test (Hu *et al*., 2007).

The Backward Spike and Forward Disc Forming (BSFDF) test has been devised to eliminate the difficulties faced in conducting the test and extracting the tested specimen. During the experiment, extraction in DCE test or FRBCE test is extremely difficult. In many cases, the test specimens have to be extricated or taken in a damaged state. BSFDF test is simple but effective in quantifying the interface friction like both the tests. The principle of BSFDF test in measuring the interface friction during forming of aluminium alloy and its effectiveness is discussed.

Backward spike and forward disc forming test: Two methods are employed in friction measurement; direct measurement techniques. In this method, interface friction is measured directly during the operation. Pin sensing test is an example where this technique is adopted. Indirect measurement techniques (Ebrahimi and Najafizadeh, 2004). In this method, interface friction is measured using the principle of flow of bulk metal. The geometrical parameters are then converted into dimensionless numbers which are used for quantifying interface friction.

BSFDF test is a new test which is coming under the group of indirect measurement techniques which by using dimensional changes of the billet, quantify interface friction.

A cylindrical billet of diameter, D and initial height, H is placed in a container. The container has in one side a counter sunk chamber with a taper angle of 14.94 degrees. The container is rigidly fixed to a bottom plate using set screws. A hollow punch of outer diameter, D with a central hole diameter, D_s presses the billet against a flat rigid bottom plate. The schematic diagram of the test setup is shown in Fig. 1.

During forming, due to the application of force there is a divided flow of material, i.e., a portion of the bulk material flows along the punch hole against the direction of tool motion, forming a backward spike and the other

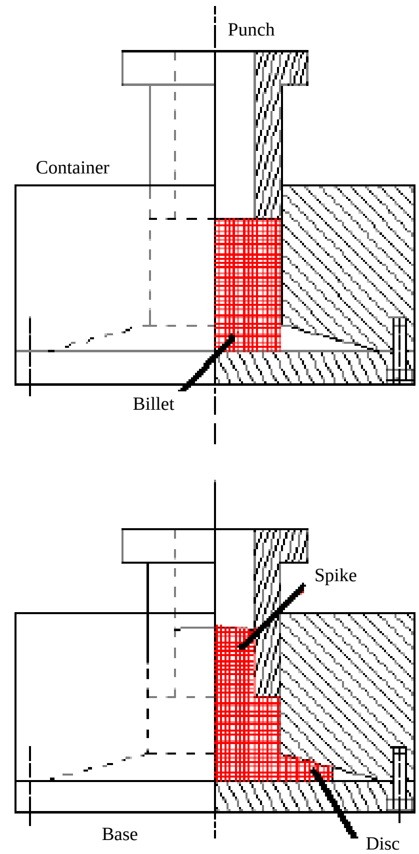

Fig. 1: Schematic diagram of the test setup

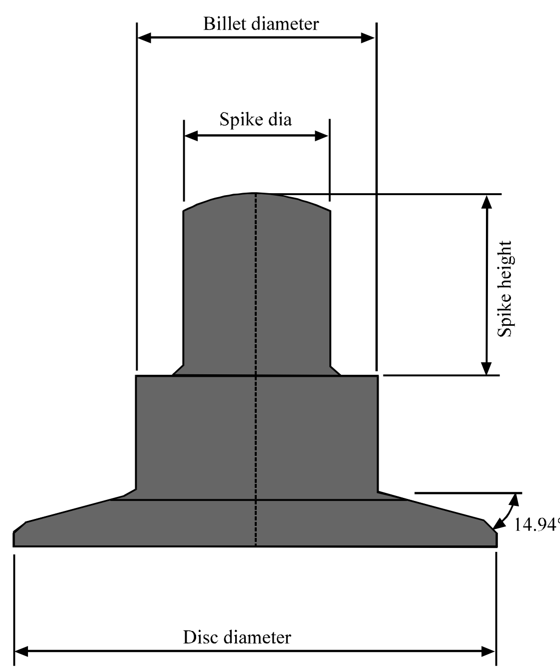

Fig. 2: Formed spike and disc specimen

portion flows and occupies the counter sunk cavity to form a circular disc. The formed test specimen is then taken out and the dimensions are measured to plot the calibration curves. The formed spike and disc specimen along with its features is shown in Fig. 2.

The spike height, H_s and the disc diameter, D_d are measured during the punch travel. The ratio, H_s/D_d is calculated to measure the interface friction. Due to the presence of the interface friction, for different friction conditions the spike heights and the disc diameters vary. These characteristics are then used for quantifying the friction. The major advantage of this test is that unlike in other tests: Twist and Compression test (Bay *et al*., 1995) for example the load or force characteristics need not be measured to arrive at the friction factor. Only geometric parameters are to be measured and processed.

The advantages of this test are: simple setup, punch and billet centre lines are collinear and do not need any special arrangement to maintain it. Removal of the formed test piece is very easy unlike in DCE or FRBCE tests for the same size of the billets and setup where extraction of the test specimens are extremely difficult no buckling of punch little influence on the results by flash formation if any.

Objectives: The main objectives of this research are:

- To ascertain the feasibility of using backward spike and forward disc forming test to measure and quantify the interface friction in forming
- To determine the optimum sizes of the tool and die setup and suitable ratio of Height/Diameter (H/D) of the test specimen
- To generate the calibration curves for various H/D values and friction conditions that may serve as the interface measuring tool during forming

MATERIALS AND METHODS

Simulation: The BSFDF test is simulated using a specialised forming/forging computer Software DEFORM-2D. It has already been established that by using DEFORM-2D package, modelling, simulation and analysis can be successfully carried out in forming operations (Oh *et al*., 1992). Evaluation of lubricants has been carried out by double cup extrusion test using DEFORM-2D (Gariety *et al*., 2006). This research also employs the DEFORM-2D for simulation.

Since, the cylindrical billet is axi-symmetrical one, a single half of the billet is considered for analysis. Simulations are carried out for 60% reduction in original height of the billet. Aluminium alloy 6063 is used as the

Table 1: AL6063 parameters

Characteristic	Description
Contents (%)	Si: 0.6% max; Mg: 0.9% max; Fe: 0.35% max; Mn: 0.15 max; Zn: 0.15% max
Grade	Annealed wrought

Table 2: Simulation parameters

Condition	Description
Punch velocity	1 mm sec^{-1}
Billet diameter	20 mm
Billet height	20 mm
Punch outer diameter	20 mm
Reduction of billet height	60%
Taper of counter sunk chamber	14.94°

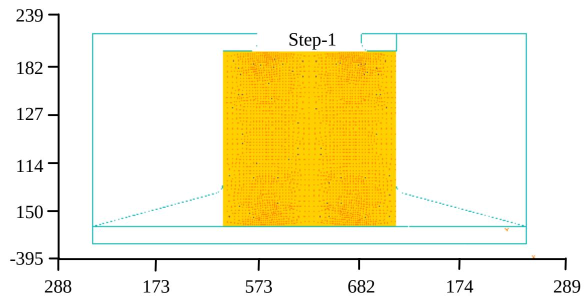

Fig. 3: Mesh of fresh billet

material for the analysis and experimental validation. The parameters of Aluminium alloy 6063 are given in Table 1. Simulation parameters are given in Table 2.

To arrive at the optimum geometric parameters, analyses have been done for various Height/Diameter ratios of the billets and for various combinations of the punch diameters and punch hole diameters.

The diameter of the cylindrical billet is chosen as 20 mm. The height of the billet is changed in different iterations as per the H/D ratios requirement. Punch outer-diameter is taken as 20 mm and the centre hole inside the punch is taken as 12 mm (spike diameter). A radius of 1 mm has been given for the facing edge of the punch. The countersunk chamber edge is also given 1 mm radius. Punch velocity is taken as 1 mm sec^{-1}.

Keeping each of the H/D ratio constant, simulations are carried out for the friction factor values 0.01, 0.03, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.4. The fresh billet fully meshed is shown in Fig. 3.

The mesh of deformed billet for m = 0.01 and m = 0.4 are shown in Fig. 4 and 5, respectively. It can be seen that when shear friction factor is low (m = 0.01) the disc diameter is more comparing to when the shear friction factor is more (m = 0.4). However, the height of the spike is less when friction is less.

The solid models of fresh billet and deformed billet are shown in Fig. 6 and 7, respectively. The spike heights

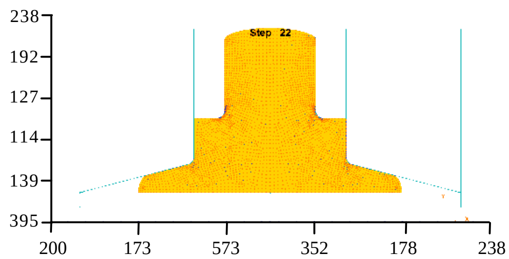

Fig. 4: Deformed mesh (m = 0.01)

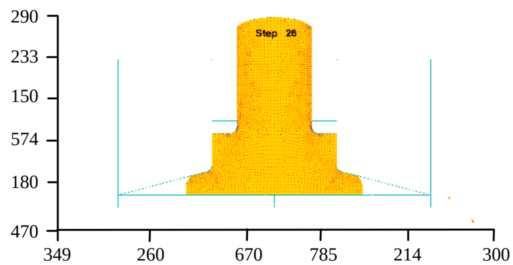

Fig. 5: Deformed mesh (m = 0.4)

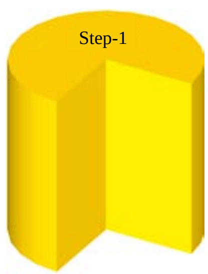

Fig. 6: Undeformed Specimen Solid Model

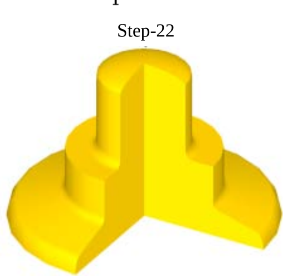

Fig. 7: Deformed Specimen Solid Model

and the disc diameters for various punch strokes are extracted from the simulations results. For each of the H/D ratio, with H_s/D_d values as y-axis values and % reduction in the billet initial height as x-axis values, calibration curves are plotted.

Simulations have been carried out for the H/D ratios 0.75, 1.0 and 1.25. For each of the H/D ratio, simulations have been conducted for spike diameters 10, 12 and 14 mm. Comparing the calibration curves for H/D = 0.75,

Fig. 8: Photographs of initial and deformed billets

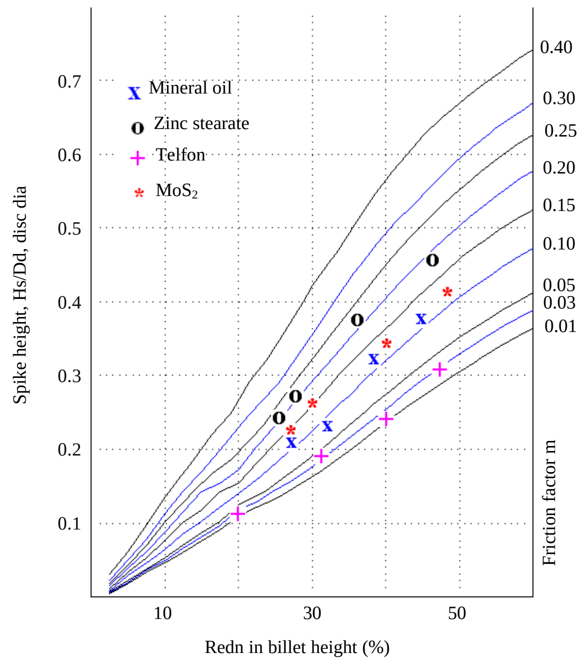

Fig. 9: Calibration curves of Backward Spike Forward Disc Forming test

1.0 and 1.25, it is observed that the sensitiveness is high and proportionate for H/D = 1.0, taper angle = 14.96° and spike diameter = 12 mm and hence the same is standardised for further simulation and experimentation.

Experimentation: To validate the above simulation results, experiments are carried out. A hydraulic press of 250 kN is used for carrying out the experiment. Punch and die setup has been made from material to specification IS:3748XT215-Cr12 (1990). The lubricants that are used in the test are teflon, zinc stearate, molybdenum disulphide and mineral oil. Due care is taken in test specimens preparation to ensure that they are without any burrs and surface with smooth finish. After the completion of each

Table 3: Friction factor values

Lubricant	Value of friction factor (m)	
	From literature	From this test
Teflon	0.02	0.03
Zinc stearate	0.19	0.20
Pure MoS_2	0.13	0.11
Mineral oil	0.12	0.10

experiment, the entire punch and die setup is cleaned, inspected for any defects and then further processed. A digital vernier with a least count of 0.01 mm is used for measuring the geometric parameter of the test specimen. The spike heights and disc diameters are measured.

The billets are placed in the container of the die setup after duly applying the lubricant under consideration. The die setup is also thoroughly applied with the lubricant. After performing each test, punch stroke, spike height and the disc diameter are recorded for further processing. The photographs of the fresh billet and deformed billet are shown in Fig. 8. The ratio of spike height to disc diameter for the percentage reduction in the billet height is superimposed on the calibration curves. The shear friction factor values are read from the calibration curves (Fig. 9) that have been already drawn using simulation. The results are compared with that have already been obtained from earlier research work. The values thus obtained and the values obtained from literature are given in the Table 3.

RESULTS AND DISCUSSION

On scrutiny and comparison of the calibration curves for H/D ratio 0.75, the sensitivity is very poor. For H/D ratio 1.25, though the sensitivity is slightly more than that of H/D 1.0 the spike growth is not proportional to the disc formation. This disproportional growth will not be suitable since any slight error will be magnified and will lead to an erroneous result. Moreover, only development of the disc represents closed forming to an accurate extent rather than spike growth. Hence H/D ratio = 1.0 is taken as the standard value for detailed simulation and experimentation.

The taper angle of the counter sunk chamber dimension is 14.96°. If this taper angle is decreased then the disc bottom surface leaves the contact with the die surface. This situation should be avoided since this will not represent the forming process truly. Calibration curves for values of m from 0.01-0.4 have been plotted for the chosen value of H/D = 1.0.

BSFDF mimics closed forming operation to a greater extent. A minimum of 10% of the punch stroke is needed before taking the measurement since till this region the sensitivity is low. But after that region, the curves are sensitive.

By superimposing the values of spike height/disc diameter ratio and the reduction in the billet initial height from the experiments, on the calibration curves, the shear friction factor of the lubricants can be obtained. The shear friction factor values thus measured for teflon, zinc stearate, molybdenum disulfide and mineral oil are shown in Fig. 9.

The retention of the lubricant that is applied during the forming operation is effective since by geometric constraint, the lubricant could not freely escape. This is not so in the other tests like Spike Forging test or Simple Upsetting test (Cecil, 2003) where special care has to be exercised to retain the lubricant. So, it can be inferred that the reliability of the results obtained by BSFDF test is good and the values from the tests are close to the actual values of the lubricants tested.

Powder and oil lubricants are most suitable to be tested by this test. Application of teflon tape instead of the Teflon spray might be the reason for the variation in the friction factor value obtained. The friction factor value shown in the Table 3 (in the literature column) is for Teflon spray.

CONCLUSION

The capability of BSFDF test to measure and quantify the interface friction during forming of aluminium alloy 6063 has been brought out in this research. The test mimics the closed forming process. In this test, surface expansion during the process is quantitatively close to that of the double cup extrusion test. BSFDF test is not as difficult as double cup extrusion test or forward rod backward cup extrusion test. The sensitiveness of the calibration curves is found to be satisfactory. Considering the overall convenience and advantage it offers, backward spike and forward disc forming test can be used to measure and quantify the interface friction in forming.

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