

## Spike and disc forming test for friction measurement in cold forming of aluminium alloys

R. Velu<sup>1</sup> and Moses Raja Cecil<sup>2</sup>

<sup>1</sup>Mechanical Department, Dr.M.G.R. University, E.V.R.Salai, Chennai-600095, India

<sup>2</sup>Design and Development Division, Integral Coach Factory, Chennai-600038, India

veluramasamy@yahoo.co.in; rajacecil@yahoo.com

### Abstract

Interfacial friction plays a vital role in cold forming and forging. Since this shear force, if uncontrolled, would lead to many defects and problems, it is essential to measure this entity and to overcome it. Using spike and disc forming test, this interfacial friction is measured. A circular billet is extruded to form a spike on one side and upset to form a disc on the other. Aluminium alloy 6063 is used as the material. Simulation is carried out for various combinations of height/diameter of the billet and for different spike diameters. The ratio of the height of the spike to the disc diameter is a measure of the friction force. This ratio is plotted to form calibration curves. Using these curves, the friction present during the cold forming process is quantified.

**Keywords:** Aluminium, friction measurement, interface friction, spike extrusion, calibration curves, lubricants

### Introduction

Cold forming is a fast, effective and efficient metal forming processes employed to manufacture a part with less material wastage. Parts with intricate features can be produced in a minimum time using cold forming process than any other processes. The effectiveness of this process has enabled it to retain an edge over others and the progress in various fields could not have been possible without the advancement in cold forming.

The soundness of the formed part depends upon many characteristics like the ability of the metal to flow and to fill up the die cavities. During forming, there exists relative movement between the tooling setup, and the billet being worked upon; hence, there arises friction in the interface between them. This interfacial friction, if uncontrolled can cause many defects like inadequate die filling, cracks and discontinuities, porous surfaces and subsurface defects in the formed part, premature wear and tear of the tool and die setup, increased energy requirements, stalling of the press/forging (Gopal, 2001). Therefore, if a quality part is to be made, this interface friction has to be controlled and kept within limits. The first step in controlling this friction is to quantify the same that arises, and then accordingly select a suitable lubricant and apply it during the forming process.

In a metal forming operation, the lubricating characteristic of a lubricant influences the interfacial friction. It is generally expressed in two terms, co-efficient of friction,  $\mu$  and shear friction factor,  $m$ .

In metal forming analysis, frictional shear stress,  $\tau$  is expressed as follows:

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

where  $\sigma_n$  is the normal stress or pressure that acts perpendicular to the surface and  $\mu$  constant co-efficient of friction (Schey J.A., 1970). This constant co-efficient of friction theory could not truly represent the bulk forming operation (DePierrie V., 1974). Hence, constant shear friction factor,  $m$  as given below, is used for analysis.

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

where  $\sigma_o$  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  $m=0$  represents frictionless interface and  $m=1$  represents sticking friction. Studies indicate (Altan *et al.*, 1983) that equation (2) represents the frictional shear stress to a greater extent in metal forming than equation (1). Usage of the shear friction factor offers a distinct advantage in evaluating 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 would affect the regular production (Henry S. Valberg, 2010). Tribological tests like Ring Compression Test, Simple Upsetting test, Spike Forging Test (Moses R. Cecil, 2003), Double Cup Extrusion (DCE) (Gopal, 2001) Test, Compression and Twist Test (Hansen & Bay, 1986) have been conducted in laboratory conditions to measure the interfacial 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, 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 Yamin *et al.*, 2007).

The Spike and Disc Forming (SDF) test has been devised to eliminate the difficulty faced in conducting the test and extracting the tested specimen. Extraction in DCE test or FRBCE test is extremely difficult. SDF test is simple but as effective as both the tests. The principle of SDF test in measuring the interfacial friction during cold forming of aluminium alloy and its effectiveness is brought out in this paper.

### Spike and disc forming test

Two types of tests are employed in friction measurement; 1) direct measurement techniques,

measure friction force directly during the operation as in pin

sensing test and 2) indirect measurement techniques (Ebrahimi & Najafizadeh, 2004) in which the friction is measured using the basic principle of flow of material and dimensionless numbers.

SDF test is a novel test which can be grouped under indirect measurement techniques which using dimensional changes, quantify interface friction.

The schematic diagram of the test setup is shown in Fig.1. A billet of diameter,  $D$  and initial height  $H$  is placed in a container. The container has a counter-sunk chamber with a taper angle,  $A$ , (Fig.2) and is rigidly attached to the 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. During the application of force, there is a divided flow of material i.e., a portion of the billet material flows along the punch hole in the direction of opposite to tool motion, forming a spike and the other portion flows and occupies the counter sunk cavity to upset a disc.

The tested specimen - spike and disc - 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. Owing to the presence of the interfacial friction, for different friction conditions, the spike heights and the disc diameters vary. These characteristics are 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; a) simple setup b) punch and billet centre lines are collinear and does not need any special arrangement to maintain it, else the cup formed will be of oval cross-section and thus would not produce correct result c) 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 either the punch is prone to breakage or extraction of the test specimens are extremely difficult d) no buckling of punch e) little influence on the results by flash formation, if any.

#### Objectives

The main objectives of this work are

- 1) To find the feasibility of using Spike and Disc Forming Test to quantify the interfacial friction in cold forming of aluminium alloys.
- 2) To determine the optimum dimensions of the Tooling setup and suitable ratio of Height / Diameter (H/D) of the billet.

Table 1. Simulation parameters

Condition	Description
Punch velocity	1 mm/s
Billet diameter	20 mm
Punch outer dia	20 mm
Reduction of billet height	60%
Taper of counter sunk chamber	14.94°

Tale 2. Aluminium alloy 6063 parameters

Parameter	Description
Contents in %	Mg - 0.9 max; Si - 0.6 max; Fe - 0.35 max; Mn - 0.15 max; Zn - 0.15 max
Grade	Annealed Wrought

- 3) To draw the calibration curves for various H/D ratios and friction conditions.

#### Methodology

The SDF 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 done using double cup extrusion test using DEFORM-2D (Mark Gariety *et*

*al.*, 2006). This work too employs the same package for simulation.

Since the problem is axi-symmetric, one half of the billet has been taken for analysis. Simulations (Table 1) are carried out for 60% reduction in original height of the billet. Aluminium alloy 6063 (Table 2) is used as the material for the analysis.

Analyses have been done for various H/D ratios of the billets and for various combinations of the punch diameters and punch-hole diameters.

As an initial iteration, a circular billet of 20 mm diameter is chosen. The height of the billet is varied as per the H/D ratios requirement. Punch diameter is taken as 20 mm with the centre-hole diameter (spike diameter) as 12 mm. A radius of 1 mm has been provided for the facing edge of the punch and die. Punch velocity is taken as 1 mm/s.

Keeping each H/D ratio constant, simulations are carried out for friction factor values 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.4.

The undeformed billet fully meshed is shown in Fig.3. The mesh of deformed billet for  $m=0.05$  and  $m=0.4$  are shown in Fig.4 and Fig.5 respectively. It may be seen that when friction factor is low ( $m = 0.05$ ) the disc diameter is more comparing to when the friction factor is more ( $m=0.4$ ). But the height of the spike is less when friction is less. The solid models of undeformed billet and the deformed one are shown in Fig.6 and Fig.7 respectively.

The disc diameters and the spike heights for different punch strokes are extracted from the simulations. For each of the H/D ratio, with  $H_s/D_d$  as ordinate values and % reduction in the billet initial height as abscissa 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 10mm, 12mm and 14mm. The calibration curves for H/D =0.75 and 1.25 are shown in Fig.8 and Fig.9 respectively.

Calibration curves for H/D=1.0 is shown in Fig.13. Comparing the Fig.8, Fig.9 and Fig.13, it may be seen that the sensitiveness is high and proportionate for H/D = 1.0, taper angle  $A = 14.96^\circ$  and spike diameter = 12mm,

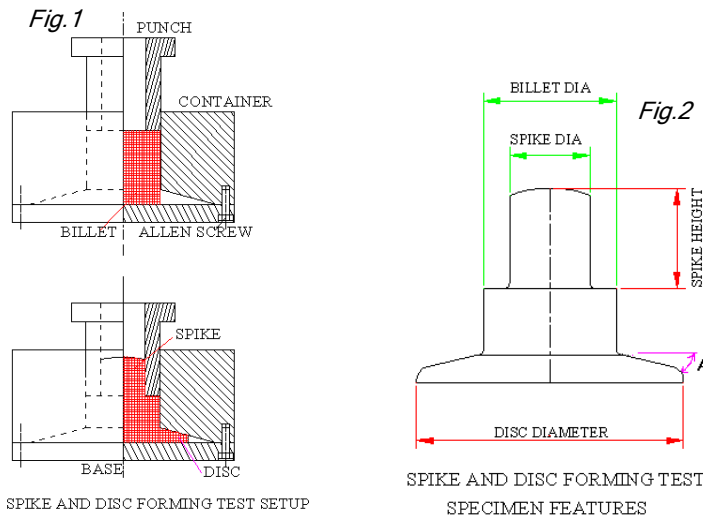


Fig.6. Undeformed solid model

Fig.7. Deformed solid model

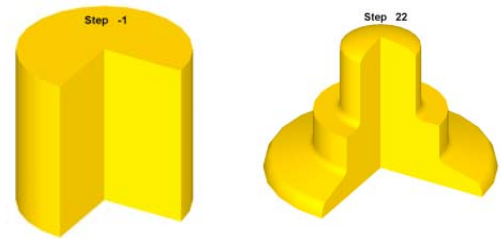


Fig.8. Calibration curves for H/D=0.75

- ① m=0.4, Spike dia = 14mm
- ② m=0.05, Spike dia = 14mm
- ③ Spike dia = 10mm, m=0.4
- ④ Spike dia = 10mm, m=0.05

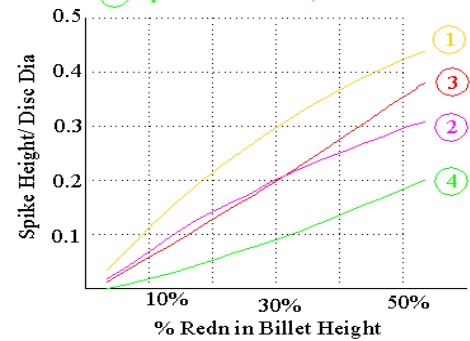


Fig.9. Calibration curves for H/D=1.25

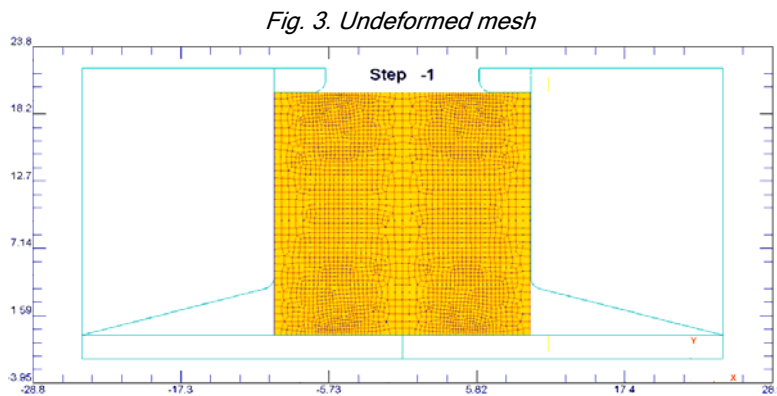
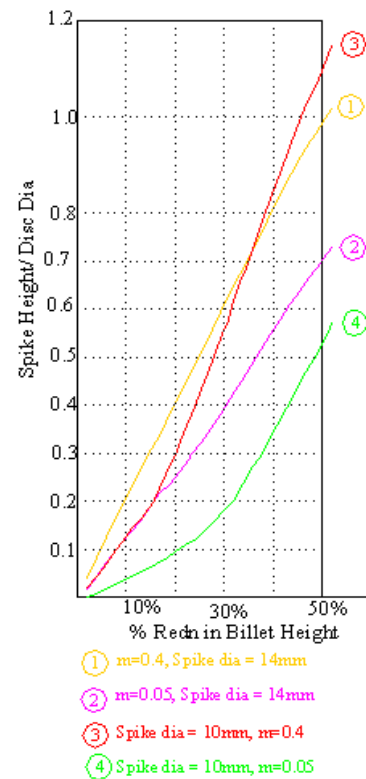


Fig.4. Deformed mesh, m=0.05

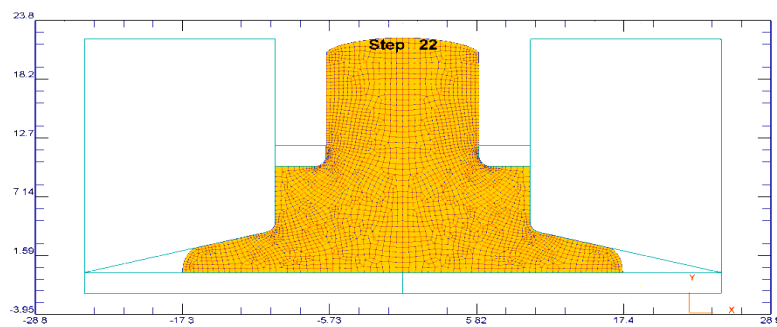
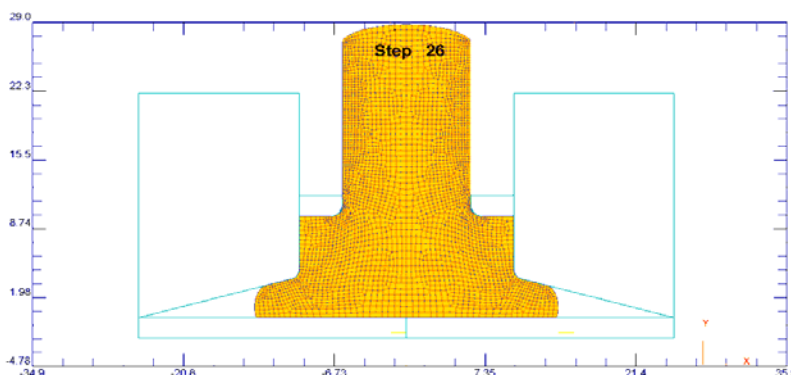


Fig.5. Deformed mesh, m=0.4



and hence the same is standardised and further simulation and experimentation.

**Experimentation**

To validate the simulation results, experiments were conducted.

The solid model of SDF test tooling setup is shown in Fig.10. A hydraulic press of 250 kN is used for conducting the experiment. Tool and die setup Fig.11 has been made from material to specification IS:3748XT215-Cr12 (1990). Teflon, Zinc Stearate, Molybdenum disulphide, and mineral oil were used as lubricants. Due care has been taken in billet preparation to ensure that they were without any burrs and surface with smooth finish. After each experiment the entire punch and die setup was cleaned, inspected for any defects and then further processed. A digital vernier with a least count of 0.01 mm was used for measurement of spike heights and disc diameters and no special measuring equipment is needed.

The billets were placed in the die setup duly applying the lubricant. The die setup has also been thoroughly applied with the lubricant. After performing each test, punch stroke, spike height, and the disc diameter have been recorded. The photographs of the fresh billet and deformed billet are shown in Fig.12. The ratio of spike height to disc diameter and the % reduction in the billet height were superimposed on the calibration curves. The friction factor values were read from the calibration curves and have been compared with that have already been obtained from previous research work. The values thus obtained are compared with the values obtained from literature reference as given in the Table 3.

**Results and discussion**

Referring Fig.8, calibration curves for H/D ratio 0.75, the sensitivity is very poor. From Fig.9, 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

Fig. 10. Solid model of SDF tooling setup

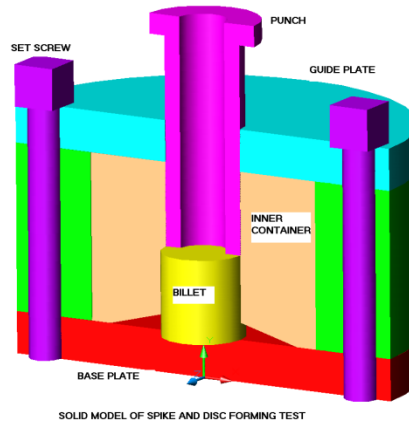


Fig. 11 Experimental setup

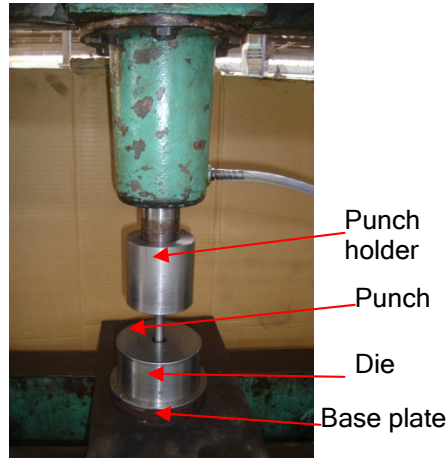


Fig. 12 Photograph of initial and deformed billets



development. This will not be suitable since any slight error in spike measurement will be magnified and will lead to an erroneous result. Moreover, development of the disc represents closed forming rather than spike growth. Hence H/D ratio = 1.0 is taken as the standard value for detailed simulation and experimentation.

The taper of the counter sunk chamber dimensions are 15 units horizontal to 4 units vertical (taper angle, 'A' is 14.96°). If this taper is decreased, then the disc bottom surface leaves the contact with the die surface. Calibration curves for values of m from 0.05 to 0.4 have been plotted for the chosen value of H/D = 1.0.

SDF mimics closed forming operation. A minimum of 10% stroke is needed before taking the measurement since till then the sensitivity is low. But thereafter the curves are sensitive upto 60% and above too.

By superimposing the spike height / disc diameter ratio and the punch stroke from the experiments, on the curves obtained from FE simulations, the shear friction factor of the lubricants can be obtained. The friction factor values thus measured for Teflon, zinc stearate, molybdenum disulfide and mineral oil are shown in Fig.13, Fig.14,

Fig.15 and Fig.16 respectively.

The retention of the lubricant during the forming operation was good since, by geometric constraint, the lubricant could not escape freely. This is not the case in other tests where special care has to be taken for this purpose. So, it can safely be inferred, that the reliability of the results obtained by this test is good and the values from the test are close to the actual values of the lubricants tested.

Powder and oil lubricants are most suitable to be tested by this test (Table 3). Application of Teflon tape was difficult and this might be the reason for the variation in the friction factor value obtained. The value from the literature for Teflon spray was applied during the process.

**Conclusions**

The capability of SDF test to measure the interfacial friction during cold forming of aluminium alloy 6063 has been brought out in this paper. The test mimics the closed forming process and is simpler than double cup extrusion test or forward rod

Table 3

Lubricant	Value of Friction factor, m	
	From literature	From this test
Teflon	0.02	0.03
Zinc Stearate	0.19	0.20
Pure MoS2	0.13	0.11
Mineral Oil	0.12	0.10

Fig. 13

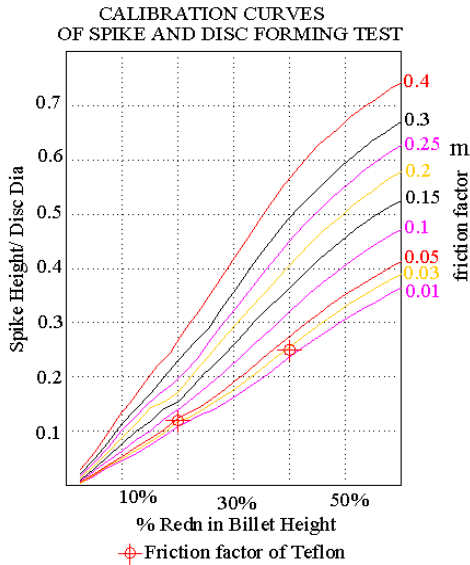


Fig. 15

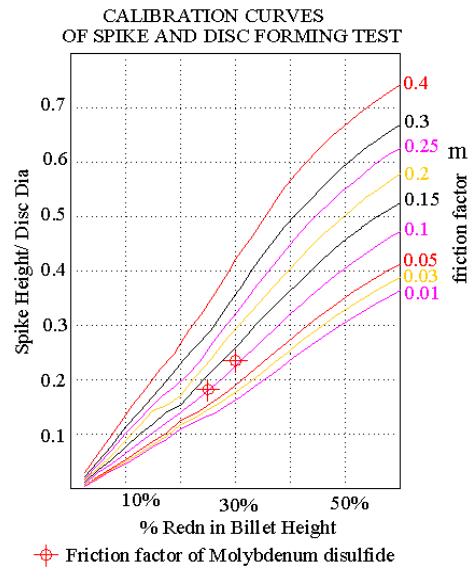


Fig. 14

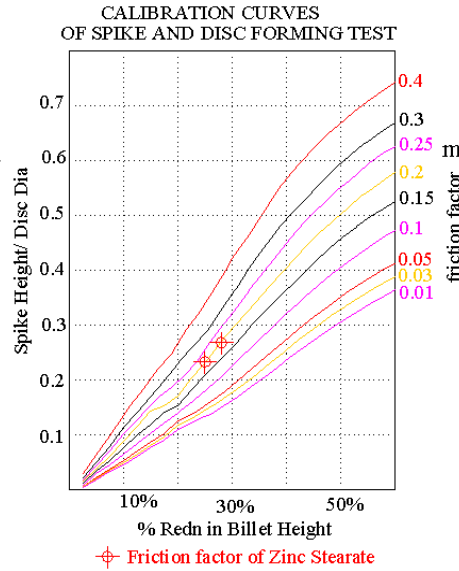
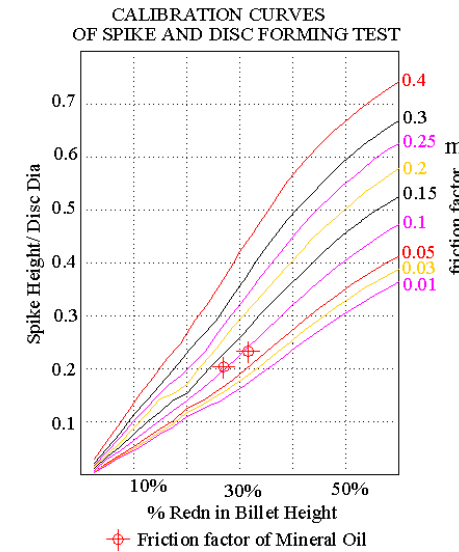


Fig. 16



backward cup extrusion test. The sensitiveness of the calibration curves is satisfactory. Considering the overall convenience and advantage it offers, Spike and Disc Forming test can be used to measure the interface friction in cold forming of aluminium alloys. Future work may be carried out to ascertain the effectiveness of this test for warm and hot forming.

**Acknowledgement**

The first author gratefully acknowledges Mr. Baby George, In-charge of Tool room Section, his team, and Mr. Gajendrababu for their assistance in carrying out the experiments.

**References**

1. Abdul NA (1981) Friction determination during bulk plastic deformation of metals. *Annals of the CIRP*. 30, 143-146.
2. Altan T, Oh, SI and Gegel HL (1983) Metal forming fundamentals and applications. ASM Metal Park, Ohio.
3. Bay N, Wibom O and Aa. Nielsen J (1995) A new friction and lubrication test forging. *CIRP Annals-Manuf. Technol.* 44 (1), 217-221.
4. DePierrie V and Gurney F (1974) A method for determination of constant and varying friction factors during ring compression tests. *Transact. ASME J. Lubrication Technol.* 96, 482-488.
5. Ebrahimi R and Najafizadeh A (2004) A new method of evaluation of friction in bulk metal forming. *J. Materials Process. Technol.* 152, 136-143.
6. Gopal M (2001) Evaluation of friction using ring compression and double cup extrusion test - an Experimental and FEM Study. Ph.D. Thesis, Anna Univ., India.
7. Hansen BG and Bay N (1986) Two new methods for testing friction for cold forging. *J. Material Working Technol.* 13, 189-204.
8. Henry S. Walberg (2010) Applied metal forming. Cambridge, UK.
9. Hu Yamin, Lai Zhoui and Zhang Yucheng (2007) The Study of cup-rod combined extrusion processes of magnesium alloys. *J. Materials Process. Technol.* 187 (188), 649-652.
10. Mark Gariety, Gracious Ngaile, Taylan Altan (2006) Evaluation of new cold forging lubricants without zinc phosphate precoat. *Intl. J. Machine Tools & Manuf.* 47, 673-681.
11. Moses R. Cecil (2003) Finite element analysis of hot forging of steel. Ph.D. Thesis, Jawaharlal Nehru Technological Univ., Hyderabad, India.
12. Oh SI, Wu WT and Tang JP (1992) Simulations of cold forging processes by the deform system. *J. Materials Process. Technol.* 35, 357-370.
13. Schey JA (1970) Metal deformation processes: friction and lubrication. Morcel & Decker Inc., NY.