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FRICTION MEASUREMENT IN COLD FORMING USING TRIBO-TESTS

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ABSTRACT

Using tribo-tests, the interface friction which exists during forming, is measured and a suitable lubricant is applied to reduce it since it is root cause for many problems. Aluminium alloy 6063 material is tested in three tribo-tests to form various shapes whose features are used to quantify friction. Forward spike and backward cup test is carried out in addition to simple upsetting test and spike forging test to evaluate friction. Forming is simulated for various ratios of height/ diameter of the billet and for different punch diameters. Calibration curves are plotted for the three tests and the ease of conducting the test and finding the shear friction factor values are brought out. Both in simulation and experimentation, different friction situations have been tested using different lubricants. By marking the values obtained from the tribo-tests on the calibration curves, the interface friction arising during the forming process is found out.

Key words: *Friction Measurement, Interface Friction, Tribo – Tests and Calibration Curves.*

1. Introduction

Cold forming is one of the fast, effective and efficient manufacturing processes used to make parts with intricate details with little or no wastage of raw materials. Mass production of many of the items without any flaws, in various fields has been possible due to the advancements in forming processes. Quality of a formed part depends upon factors like the metal flow and complete filling up of the die cavity. During forming, due to the relative motion between the tool and die setup, and the bulk metal being processes, there arises skin friction in the interface between them. This interface friction is shear in nature and is the cause for many potential defects and difficulties such as inadequate filling up of metal in the cavity, cracks and porous surfaces, subsurface defects in the formed part, premature wear and tear of the tool and dies setup, increased energy requirements, stalling of the press/forge [1]. Therefore, if a fit part is to be produced, the interface friction has to be kept under control. The first step in controlling this friction is to measure it, and then accordingly apply a suitable lubricant during the process.

In a metal forming operation, the interface friction during the process is generally expressed in two terms, co-efficient of friction, μ and shear friction factor, m.

In the analysis, two friction models namely Coulomb friction model and Tresca Friction model are used to describe them. In Coulomb's theory, frictional shear stress, τ is expressed as follows:

$$\tau = \mu * \sigma_n \qquad (1)$$

Where σ_n is the normal stress or pressure that acts normal to the surface and μ is the co-efficient of friction [2]. Since τ cannot increase beyond the ultimate shear strength of the formed bulk material, any increase in the normal stress should reduce the friction as per Eq. (1). But in reality this is not so and hence this constant co-efficient of friction theory could not exactly represent the bulk forming operation [3].

Tresca's friction model equates the shear stress to a constant shear friction factor, m as follows:

$$\tau = (m * \sigma_o) / \sqrt{3} \qquad (2)$$

Where σ_o is the flow stress of the billet material. The flow stress is a property of the billet material and it depends upon the strain, strain rate and temperature of the billet. The value of shear friction factor varies from 0 through 1. Frictionless interface is represented when m is zero and sticking friction when m is one. Studies indicate that Eq. (2) represents the frictional shear stress to a closer and accurate extent in metal forming than Eq. (1) [4]. Therefore, shear friction factor is widely used in evaluating friction and load calculations. To measure this shear friction factor, many tribo-tests have been conducted.

During mass manufacturing in a production shop, it is impractical to measure the interface friction

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since this would affect production and the cost will be also high when something goes wrong [5]. Tribological tests like ring compression test, simple upsetting test (SUT), spike forging test (SFT)[6], double cup extrusion test (DCE) compression and twist test [7] have been conducted in laboratory situations to measure the interface friction. These tests differ in their aspects of the complexity of the setup and their capacity to simulate the exact production conditions. The convenient test is ring compression test [8] and a complex test is compression and twist test [9]. It has been tried to measure the interface friction of magnesium alloys using Forward Rod Backward Cup Extrusion (FRBCE) test [10].

Three tribo-tests SUT, SFT and FRBCE test are carried out in same conditions and the test that is easy to conduct but accurately measures the friction is suggested. Both the SUT and SFT do not need an elaborate setup. FRBCE test combines the features of both spike forging test and DCE test. In DCE test there are two punches simultaneously moving against the billet to form two cups, whereas in Forward Rod Backward Cup Extrusion Test one side a punch will be piercing the billet against a die with a central hole. As a result, in the punch side a cup will be formed and in the die side a rod will be extruded. The functional advantage of the FRBCE test is that the test piece can be removed from the setup easily because of the fact that unlike DCE test only one cup is there and hence removal is easy.The capabilities of the three tests in measuring the interface friction during cold forming of aluminium alloy as formed material is brought out in this paper.

2. Tribological Test

Pin sensing test - direct measurement technique measures friction force by the pins embedded in the setup. Since much difficulty is faced in embedding the pins and involvement of force measurement devices, another method called as indirect measurement technique is adopted. In the indirect method, the interface friction is measured using the basic principle of flow of material and dimensionless numbers [11]. Force measurement is not required to find friction. The three tests under study also adopt the indirect measurement technique.

In simple upsetting test, a billet of diameter, D and initial height H is placed in between two rigid parallel platens and compressed to 50% of H. The billet takes a cask like shape. The ratio of diameters in the middle to that of the face is the measure of friction. In spike forging test the only difference is the top platen is having a hole in the centre through which a spike grows.

The height of the spike is a measure of friction. The ratio of billet diameter to the hole diameter is 20:11. In FRBCE test a billet of diameter D and height H is placed in a container. A punch of diameter, D_p presses the billet against a die with a central hole of diameter, D_r. During the movement of punch, there is a divided flow of material i.e., the billet material flows against the tool, forming a cup and flows through the die, forming a rod. The schematic diagrams of the SUT, SFT and FRBCE test setup are shown in figs.1, 2 and 3 respectively.

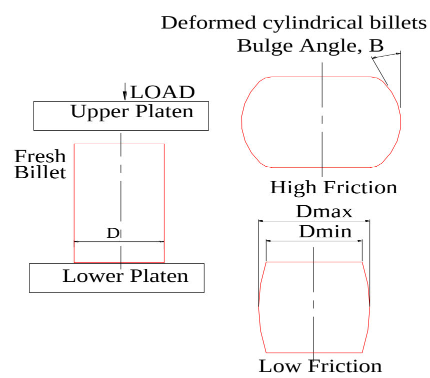

Fig. 1 Schematic Diagram of the SUT Setup

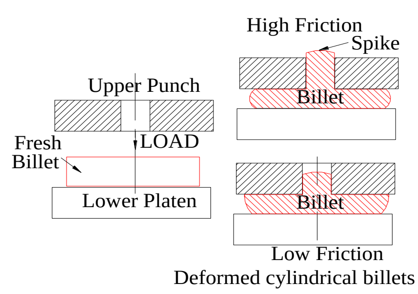

Fig. 2 Schematic Diagram of the SFT Setup

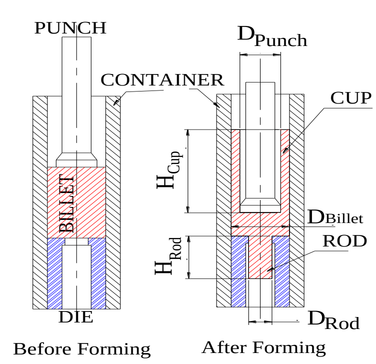

Fig. 3 Schematic Diagram of the FRBCE Test Setup

The cup height, H_{cup} and the rod height, H_{rod} are measured during the punch travel. Due to the presence of the interface friction, for different friction conditions, the cup heights and the rod lengths vary. The ratio H_{cup}/H_{rod} is a measure of friction.

The major advantage of these tests is only geometric parameters are to be measured and processed. Measurement of the parameters is also relatively convenient and easy since the tests do not need any special measuring instruments. In SUT there is no difficulty in removal of work piece but a slight difficulty is faced in spike forging. When compared to the DCE test, removal of the formed test piece is easy in the FRBCE test. But SUT and SFT represent pen forging whereas FRBCE represents closed forging.

3. Objectives

The primary objectives of this study are

i. To find the effectiveness of using simple upsetting test, spike forging test and forward rod backward cup extrusion test to quantify the interface friction in cold forming of aluminium alloys.
ii. To determine the optimum dimensions of the billets and tooling setup.
iii. To draw the calibration curves for various H/D ratios and tool diameter/ die-hole diameter and friction conditions for the three tests.
iv. To find the best one out of the three tests for open forming and closed forming.

4. Methodology

The entire process of all the SUT, SFT and FRBCE test are simulated using a specialised forming / forging computer software DEFORM-2D.

It has been brought out that by using DEFORM-2D package, modelling, simulation and analysis can be successfully carried out in forming operations [12]. Testing of lubricants has been done using double cup extrusion test using DEFORM-2D [13]. This work also employs the same software for simulation.

After finding suitable H/D ratio from the simulation results, experimentation is carried out to validate the results. A comparison of the shear friction factor values available in the literature is also done.

5. Simulation

Since the billet is axi-symmetric, half of the billet is taken for analysis. Simulations are done for 50% reduction in original height of the billet. The simulation parameters are given in Table 1.

Table 1: Tribo-Test Simulation Parameters

Parameter	Description
Punch velocity	1 mm/s
Billet diameter	20 mm
FRBCE punch diameter	14 mm
FRBCE Die internal diameter	8 mm
SFT punch hole	11mm
Reduction of billet height	50%
Shear friction factor, (m)	0.01, 0.03, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.4

Simulations have been done for various H/D ratios of the billets and for various combinations of the punch diameters and die-hole diameters. Aluminium alloy 6063 is used as the material for the analysis. Aluminium Alloy is a commonly used architectural material in the manufacturing of rail passenger coach. The physical, chemical and technological properties of Aluminium alloy 6063 was first inspected and ensured both destructively and by other means before taken for test. The flow stress curve has been constructed using simple upsetting test and the same is the input used in DEFORM-2D. The characteristics obtained from both the chief Chemist and Metallurgist Laboratory and the simple upsetting test have been applied in DEFORM-2D during simulation.

The material chemical composition is of standard values from Indian Standards for Aluminium alloy 6063. The chemical composition of the alloy is given in Table 2.

Table 2: Aluminium Alloy 6063 Parameters

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

The height of the billet is varied as per the H/D ratios requirement in all the three tests. In FRBCE test the punch and die-hole diameters are also varied as per the Punch diameter / Die-hole (or Rod) diameter (D_p/D_r) requirement. A radius of 1 mm is provided for the facing edge of the punch and die. For all the three tests the punch velocity is taken as 1 mm/s. During the simple upsetting test to find the flow stress, the velocities considered were 1m/s and 70m/s. Though aluminium alloy 6063 is considered to be strain rate sensitive there has been no appreciable change (less than 5%) in the calibration curves for the strain rate (punch velocity) of 1m/s (obtained in hydraulic forming press) and 70m/s (obtained in pneumatic forging machine). Hence the calibration curves for strain rate (punch velocity = 70m/s) has not been provided.

For SUT the ratio of middle section diameter to end face diameter is taken in y-axis and the reduction in billet height is taken in x-axis and the calibration curves are drawn. A sample FE mesh of undeformed billet and deformed billet of SUT is shown in fig.5.

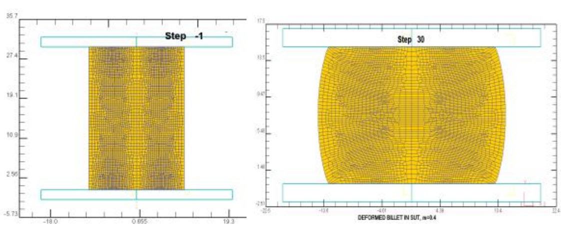

Fig. 5 Mesh of Initial and Deformed Billet of SUT

For SFT the height of the spike is taken in y-axis and the reduction in billet height is taken in x-axis and the calibration curves are drawn. A sample FE mesh of undeformed billet and deformed billet of FRBCE test is shown in fig.6.

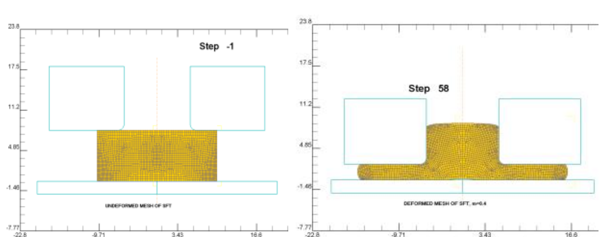

Fig. 6 Mesh of Initial and Deformed Billet of SFT

In FRBCE test, keeping each H/D ratio constant, simulations are carried out for various D_p/D_r. A sample FE mesh of undeformed billet and deformed billet of FRBCE test is shown in fig.7.

For each H/D ratio, a graph with H_{cup}/H_{rod} on y-axis and % reduction in the billet initial height on x-axis, calibration curves are plotted. These curves provide the values of shear friction factor, m. The calibration curves for values of m from 0.01 to 0.4 for SUT, SFT and FRBCE test have been shown in figures 9, 10 and 11 respectively.

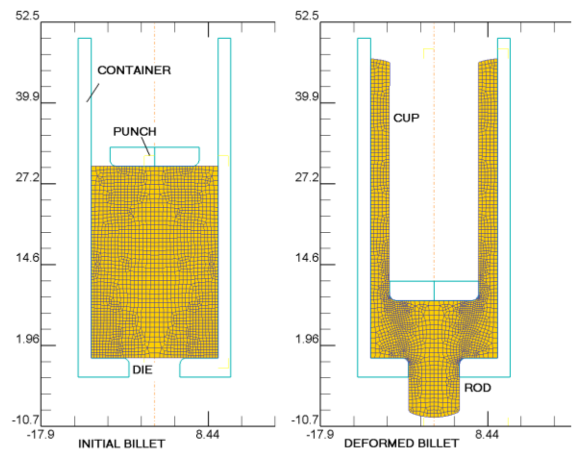

Fig. 7 Mesh of Initial and Deformed Billet of FRBCE Test

From simulation results, it is found that for H/D ratio 1.5 will be suitable in SUT, 0.4 for SFT and values of 1.5 for H/D and 1.75 for D_p/D_r are considered for experimentation so that accurate measurements can be conveniently taken.

6. Experimentation

To validate the findings of the simulation the test has been carried out using the setup described below. A hydraulic press of 250 KN is used for conducting the experiment.

The punch and die have been made from EN27. 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 was smooth. After each trial the entire and die setup was cleaned and inspected for any defects and then further processed. A digital vernier and a depth gauge with a least count of 0.01 mm were used for measurement of cup and rod features of the lubricants. The readings recorded were then superimposed on the calibration curves to get the friction factor values. The photographs of the initial and deformed billet are shown in fig. 4.

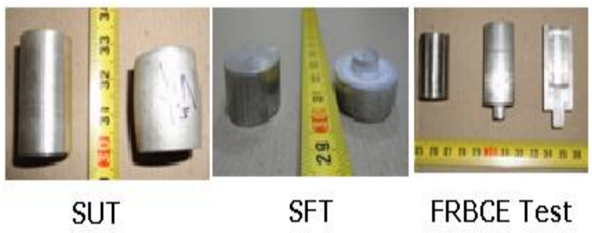

Fig. 8 Photographs of Undeformed and Deformed Billets

7. Results and Discussions

Referring to the figures 9 [14], 10 and 11, the following points have been observed.

i. Minimum compression of the billet should be 10% of the billet initial height for the results to be truly reflective. If the measurements are taken below 10% the H_{cup}/H_{rod} will be abnormal and be unsuitable for consumption. From 10% through 50% the results are truly reflective of the friction measurement test and can be relied upon. In FRBCE test till 10% there is no appreciable formation of rod and hence H_{cup}/H_{rod} is abnormally high making the ratio unsuitable for use. When the stroke is increased, above 10% and upto 50% of the height, the features of the FRBCE test piece could be measured accurately.

ii. For Simple Upsetting Test, H/D value is 1.5 and for FRBCE test H/D value standardized is 1.5. External diameter of the cup to diameter of the rod is 1.75.

iii. During this work, the results of the spike forging test are wayward and not reliable.

iv. The FRBCE test is useful in low and medium surface expansion region whereas SUT only in low surface region.

v. Due to any irregularity, if a slight eccentricity of 0.1 mm is there, then the results varied widely and hence there should not be any room for this eccentricity. Therefore the punch axis should be exactly coinciding with the centre line of the die and billet. To ensure that there is no buckling or breakage of the punch, the punch material should be adequately strong. A rigid setup and less strain rate may overcome this issue.

vi. The ends folding have been observed in SUT above 50% reduction of height and hence thereafter it ceases to measure the friction correctly. In FRBCE test the spike grows rapidly than the cup after 50% of height reduction as observed from the steep fall of the calibration curves.

vii. As observed from the SFT calibration curves the sensitiveness is very poor. The results during this experiment are also not truly reflective.

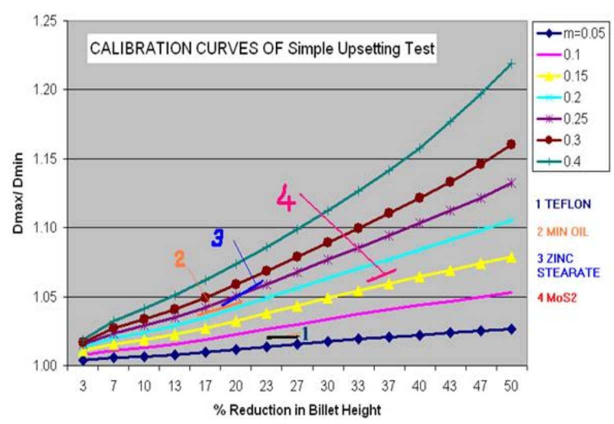

Fig. 9 Calibration Curves of SUT

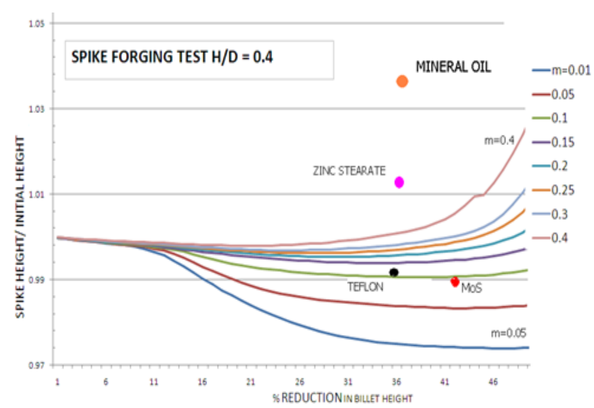

Fig. 10 Calibration Curves of SFT

The shear friction factor values read from the calibration curves of the three tests along with the values available in the literature are given in the Table 3. As observed, the values for SUT are slightly on the higher side than FRBCE.

Table 3: Friction Factor Values of Tested Lubricants

Lubricant	Shear friction factor (m) value			
	From this work			Literature Value
	SUT	SFT	FRBCE	
Teflon	0.06	0.1	0.06	0.05
Zinc Stearate	0.25	-	0.23	0.19
Mineral Oil	0.2	-	0.2	0.12
Molybdenum disulfide	0.16	0.1	0.15	0.12

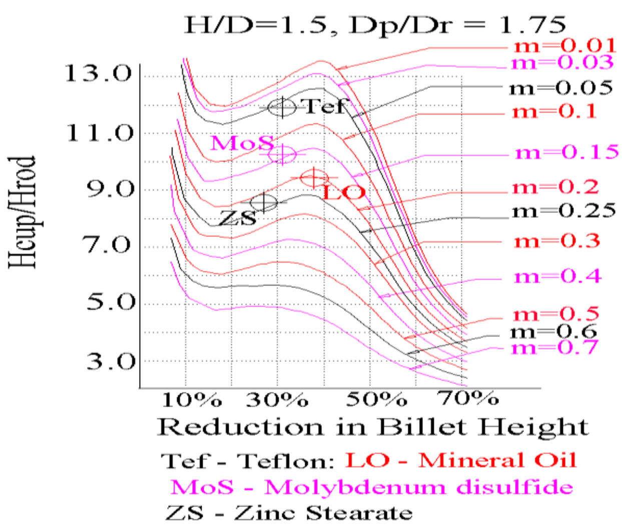

Fig. 11 Calibration Curves of FRBCE Test

8. Conclusions

The capability of SUT, SFT and FRBCE test to measure the interface friction during cold forming of aluminium alloy 6063 has been brought out. For open forming with simple setup SUT can be employed to find the friction factor closely though FRBCE will be still accurate. For closed forming, only FRBCE test out of the three can be employed since this test can accurately evaluate interface friction in cold forming of aluminium alloys. Further work is being carried out to ensure the effectiveness in warm and hot forming.

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Nomenclature

Symbol	Meaning	Unit
m	**Shear friction factor**	Dimensionless
μ	**Friction coefficient**	Dimensionless
D	**Diameter of the billet**	m
σ_o	**Flow Stress**	N/m^2
σ_n	**Normal Stress**	N/m^2
H	**Height of the billet**	m
D_p	**Diameter of the Cup**	m
D_r	**Diameter of the rod**	m
H_{cup}	**Height of the cup**	m
H_{rod}	**Height of the rod**	m

