Analysis of friction factor by employing the ring compression test under different lubricants

E. Rajesh, M. SivaPrakash

Abstract— The technology advancement has envisaged going for near net shape of the produces. Also, near net shapes formed are again cold upset for obtaining a final shape of the Product. This work deals with an experimental, theoretical and analytical determination of friction factor 'm' for Solid aluminium Cylinders under different lubricating conditions. The aluminium ring having a standard ratio specified by the Male and Cockcroft (6:3:2) with a dimension of Outer diameter: inner diameter: Height, 42:21:14 is prepared to carry the ring compression test, to determine the friction factor between the interface of the work piece and die. Different lubrication conditions are applied such as zinc stearate, molybdenum disulphide, graphite powder and in dry condition. The friction factor is sensitive to contact between the specimens and die. When the lubricant applied, the aluminium ring dimensions are change. The change in dimension, outer diameter, internal diameter, and reduction in height, using the standard calibration curve available for friction conditions by Male and Cockcroft is used to determine the friction factor of material. Aluminium specimen is applied by the load. Deformations take place, the dimensions of specimen changes. Substituting the initial undeformed geometries and the changes in the dimensions in following equations Give the value of the friction factor.[Ettouney and stelson, 1990: Male and depierre, 1970: avitzur, 1986] the friction factor is determined. When the lubricants are applied on aluminium ring under ring compression test. The load applied to the ring during ring compression test is insensitive to friction condition.

Index Terms—Friction factor, different lubricant conditions, ring compression test,

1 INTRODUCTION

Friction at the interface of die/work piece is an important variable and has significant effects on both the work piece and process variables such as deformation load, metal flow and surface quality, and internal structure of the product in metal forming processes. Therefore, the interface friction has to be understood and controlled. For effective friction control, effects of the deformation process variables, such as deformation speed, material type, and lubrication, must be treated together to investigate interaction effects among these variables.

There are several methods developed for quantitative evaluation of friction at the die/work piece interface in metal forming processes. Among all common methods for measuring the friction coefficient, the ring compression test has gained wide acceptance. This technique utilizes the dimensional changes of a test specimen to arrive at the magnitude of friction coefficient.

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For a given percentage of height reduction during compression tests, the corresponding measurement of the internal diameter of the test specimen provides a quantitative knowledge of the magnitude of the prevailing friction coefficient at the die/ Work piece interface. If the specimen's internal diameter increases during the deformation, friction is low; if the specimen's internal diameter decreases during the deformation, the friction is high. Using this relationship, specific curves, later called friction calibration curves, were generated by Male and Cockcroft relating the percentage reduction in the internal diameter of the test specimen to its reduction in height for varying degrees of the coefficient of friction. His results showed that the coefficient of friction tended to increase with an increasing deformation rate for different metal under dry condition and with a solid lubricant. Male and Cockcroft's standard ring geometry of 6:3:2 was used.

The most accepted one is to define either a coefficient of friction, m, specifically; the Coulomb law of friction or the interface frictional shear factor, m, a value varies from zero for frictionless interface to one for sticking friction. Although neither of them has universal acceptance for general cases, one or the other approach may be useful for a particular case. Among all common methods for measuring the friction coefficient, the ring compression test has gained wide acceptance. It was originated by Kunogi and later improved and presented in a usable way by Male and Cockcroft. This technique utilizes the dimensional changes of a test specimen to arrive at the magnitude of friction coefficient.

When a flat ring specimen is plastically compressed between two flat platens, increasing friction results in an inward flow of the material, while decreasing friction results in an outward flow of the material as schematically shown in Fig. 1.

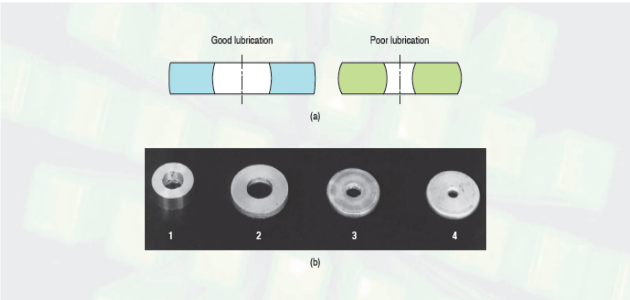

FIGURE .1 (a) The effects of lubrication on barreling in the ring compression test. (a) With good lubrication, both the inner and outer diameters increase as the specimen is compressed; and with poor or no lubrication, friction is high, and the inner diameter decreases. The direction of barreling depends on the relative motion of the cylindrical surfaces with respect to the flat dies. (b) Test results: (1) original specimen, and (2-4) the specimen under increasing friction. *Source:* A.T. Male and M.G. Cockcroft.

If the specimen's internal diameter increases during the deformation, friction is low; if the specimen's internal diameter decreases during the deformation, the friction is high. Using this relationship friction calibration curves, were generated by Male and Cockcroft relating the percentage reduction in the internal diameter of the test specimen to its reduction in height for varying degrees of the coefficient of friction as shown in Fig. 2.

After Male and Cockcroft published their well-known paper, there has been a great deal of research in order to justify its validity. Avitzur and Hawkyard and Johnson analyzed hollow disk theoretically assuming uniform distortion, i.e., no barreling, no strain hardening and most important, a constant interface friction shear factor, m. Male carried out a study in order to obtain variations in the friction coefficient of metal during compressive deformation at room temperature. His results showed that the coefficient of friction tended to increase with an increasing deformation rate for different metal under dry condition and with a solid lubricant. Later, Male also investigated the applicability of ring compression test to typical metal forming processes. Male and DePierre then investigated the validity of constant interface friction shear factor in order to characterize interfacial friction conditions during forging operation of hollow disk. They also found that Avitzur's solution gave inaccurate values for m when the Male and Cockcroft's standard ring geometry of 6:3:2 was used, in fact, it doubled the true value of m. Since both m and m were often used to characterize the same friction phenomenon at the die/workpiece interface, Male et al.

Conducted a research in order to see which one more realistically defines friction condition in metal forming processes. They showed that m as a quantitative index for defining friction conditions in upset forging operations was more realistic than m which underestimated frictional components of the deformation load. It was also found that the ring compression test is an accurate technique to determine true stress-true strain curve in typical metal forming operations and its accuracy was shown at high temperature and low strain rates.

2. OBJECTIVES

The objective of this project work is,

- To experimental, theoretical and analytical determination of friction factor (m) of aluminium ring under various lubrication conditions such as dry condition, lubricant as zinc stearate, molybdenum disulphide and graphite powder.
- Selection of the specimen dimension for the experimental analysis.
- Study and analysis the effect of load condition applied to the specimen under ring compression test and effect of loading in interface friction.

3. METHODOLOGY

3.1 Experimental Details

The simple Cockcroft and Male Ring Compression Test will be used to conduct the course of friction trials throughout this project work. As indicated earlier, this method depends on the variations in the annular specimens dimensions when subjected to compression. The reduction in height, increase or decrease of the internal diameter, external diameter determines the coefficient of friction under various lubrication conditions.

3.2 specimen material and dimensions

Aluminium is selected as the material. Aluminium rod is machined under lathe. The specimens were cut to size as per the specification that is outer diameter: inner diameter: height as 6:3:2.and is all examined in the as-received conditions. To ensure similar surface roughness, the same cutting and preparation techniques were applied to produce all the specimens.

Fig.3 Aluminium specimen

Outer diameter, D	=	42mm
Inner diameter, d	=	21mm
Height, H	=	14mm

D: d: H = 6: 3: 2

3.3 RING COMPRESSION TEST

- The method of free ring compression is the most widely applied method for determining contact conditions in bulk forming processes; therefore it is treated as the standard, universal method for determining factor of friction.
- Originally, it was conceived as the qualitative method for comparing the lubrication conditions to the influence of various lubricants onto the contact friction in cold extrusion processes, as prescribed by Kunogi in 1954.
- The method consists of monitoring the changes of inner diameter of the ring which is being compresses, because the changes are considered to be the representatives of the level of sensitivity to active contact friction.

- Friction factor is determined from these charts from the percent reduction in height and by measuring the percent change in the internal diameter of the specimen after compression.

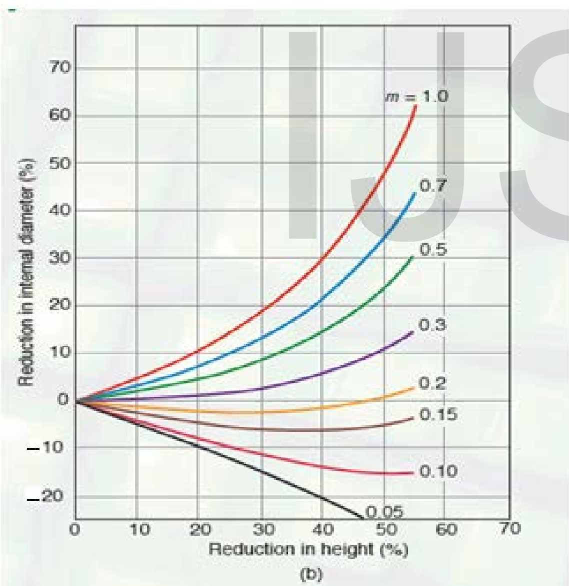

Fig.4 friction factor calibration curve

- Graphic dependence between height strain and inner diameter strain, at various influences of friction, gives calibration curves for reading the value of coefficient / factor of friction.
- When a short, hollow cylinder is compressed axially between flat, parallel, rigid platens the diameter of the hole may either increase, decrease, or remain constant according to the amount of frictional constraint imposed by the platens.
- Under frictionless conditions the hole size increases proportionately to the outer diameter; and, the cylinder compresses as would the corresponding portion of a compressed solid cylinder.
- With increasing frictional constraint, the rate of expansion of the hole decreases and eventually the compressive hoop stress developed at the hole is sufficient to cause the hole to contract.
- This has the effect that the hole may initially increase in diameter and then contract. By suitably choosing the initial proportions of the cylinder, dimensional changes of the hole can thus provide a sensitive indication of the platen friction.
- Male and Cockcroft established the calibration curves by experimental method, assuming μ-friction in inter-contact of ring and tool. The initial dimensions of the ring in the following ratio, outer diameter: inner diameter: height = 6:3:2 were adopted as standard dimensions in ring test method.
- In this test, a ring specimen is compressed between the flat parallel tools and the coefficient of friction is determined on the basis of the change in the inner diameter of the ring using calibrated curve.
- Since this method does not require the determination of the load, it has been frequently used for estimating friction during forging without large expansion of a billet surface.

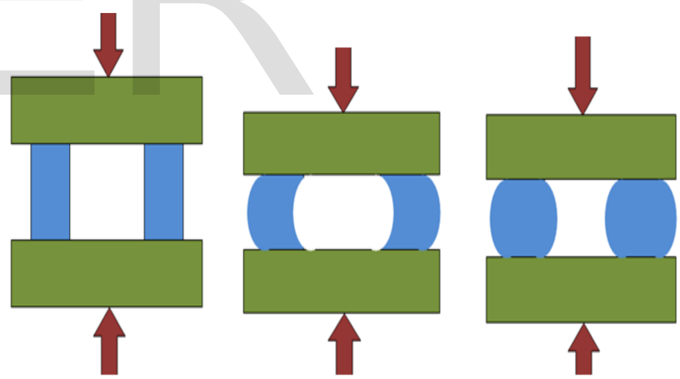

Fig.5 Ring specimen (a) before compression, (b) after compression with low friction and (c) after compression with high friction.

4. WORK PLAN

4.1 Experimental Procedure

The Experimental procedure was devised by the authors and strictly followed over the range of all experiments. The Non-related parameters such as the compression speed, the die surface roughness, and the environment temperature and humidity, were all kept at constant values.

Procedure Steps For Dry Condition

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- All examined specimens have the same dimension ratio of (OD: ID: H = 42: 21 : 14).
- Initial thickness, specimen inner and outer radius (or diameters) were measured and recorded.
- Specimen freely placed on the lower die in a way that center lines of both coincided.
- The press then started pressing the specimen at a constant speed of (0.5 mm/min).
- When the specimen was compressed, it was released.
- The new thickness, inner and outer diameters were measured. However, due to barrelling and irregularity on both inner and outer cylindrical surfaces of specimen, several diametric readings were taken and an average value was recorded.

Procedure Steps For Lubricated Conditions

In addition to the above steps, the specimen and dies contacting surfaces were
lubricated before compression. Using different lubricants like,

- Zinc stearate,
- Molybdenum disulphide (MoS2),
- Graphite powder

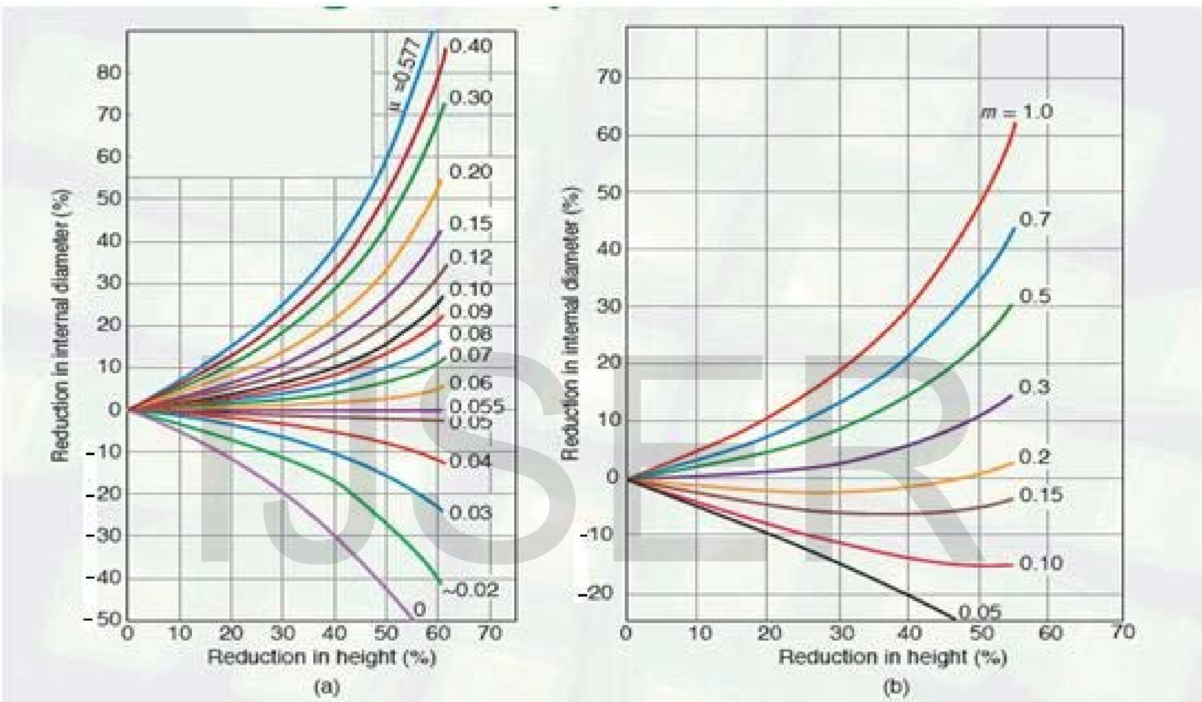

Fig.6 Friction coefficient & Friction factor calibration curve

4.2 Theoretical Procedure

Aluminum specimen is applied by the load. Deformations take place, the dimensions of specimen changes. Substituting the initial undeformed geometries and the changes in the dimensions in following equations give the value of the friction factor.

[Ettouney and stelson, 1990: Male and depierre, 1970: avitzur, 1986]

$$m = \frac{-1}{2\frac{Ro}{T}\left(1+\frac{Ri}{Ro}-2\frac{Rn}{Ro}\right)} \times \ln\left[\left(\frac{Ri}{Ro}\right)^2 \times \frac{\left(\frac{Rn}{Ro}\right)^2+\sqrt{3+\left(\frac{Rn}{Ro}\right)^4}}{\left(\frac{Rn}{Ro}\right)^2+\sqrt{3\left(\frac{Ri}{Ro}\right)^4+\left(\frac{Rn}{Ro}\right)^2}}\right]$$

$$Rn = Ro\sqrt{\frac{(Ri/Ro)+(\Delta Ri/\Delta Ro)}{(Ro/Ri)+(\Delta Ri/\Delta Ro)}}$$

$$\mu = \frac{m}{\sqrt{3}}$$

Where,

Rn - Mean radius of specimen.

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Ri -Inner radius of specimen after deformation.

Ro -External radius of the specimen after deformation.

ΔRi -Change in internal radius of the specimen after deformation.

ΔRn -Change in external radius of the specimen after deformation.

T - Height of the specimen.

m -Friction factor.

μ - Coefficient of friction.

Specimen after deformation

Dry condition

Zinc stearate

Graphite powder

Molybdenum disulphide

5. RESULT AND DISCUSSION

Since the metal forming induces high friction and heat generation at the interface between the tools and the work piece, interfacial friction has a significant effect on the forging applications, impacting die-wear, forming quality, and the deformation loads under both dry and lubricated conditions. The lubricity of lubricants is one of the most significant factors since it directly determines the interface friction, which in turn influences the stresses, the forging load, and the forging energy. In this study, the interface coefficient of friction and friction factor between the work piece and tools was determined under both dry and lubricated conditions.

The result obtained is as shown in the table. From the table it is clear that the interface friction can vary under different lubrication condition. The specimen having dimension as outer diameter 42mm, inner diameter 21mm and height 14mm,is used for the analysis but the dimension change occurred under the ring compression is different for the each lubrication condition.

The calibrated curve by the Male and Cockcroft of dimension ratio outer dia.: inner dia.: height (6: 3: 2) is used to determine the friction coefficient the result as follows,

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Experimental determination of friction factor

Lubricant condition	Load, Tonne	Final readings, mm			Reduction in inner diameter	Reduction in height	Friction factor	Friction coefficient
		Do	Di	H	$(\Delta Di/Di)\times 100$	$(\Delta H/H)\times 100$	m	μ
Dry condition	80	47	16	9.5	23.8	32.14	0.88	0.52
Zinc stearate	80	48.2	19	9.5	9.52	32.143	0.48	0.14
Graphite	80	47.8	18.8	9.8	10.48	30	0.6	0.16
MoS2	80	48.6	19	9.5	9.524	32.14	0.52	0.14

Theoretical determination of friction factors

Using the equations established by Ettouney and stelson, 1990: Male and depierre, 1970: avitzur, 1986 the friction factor is determined is shown in table.

Lubricant condition	Load, Tonne	Inner diameter Ri	Outer diameter Ro	Height H	ΔRi	ΔRo	Rn	m	μ
Dry condition	80	8	23.5	9.5	2.5	2.5	13.71	0.82	0.48
Zinc stearate	80	9.5	24.1	9.5	1	3.1	12.06	0.34	0.19
Graphite	80	9.4	23.9	9.8	1.1	2.9	12.28	0.44	0.25
MoS2	80	9.5	24.3	9.5	1	3.3	11.97	0.33	0.19

Comparison between Theoretical and Experimental results

Lubricant condition	Load, Tonne	Friction factor		Coefficient of friction	
		Exp	The	Exp	The
Dry condition	80	0.88	0.82	0.52	0.48
Zinc stearate	80	0.48	0.34	0.14	0.19
Graphite	80	0.6	0.44	0.16	0.25
MoS2	80	0.52	0.33	0.14	0.19

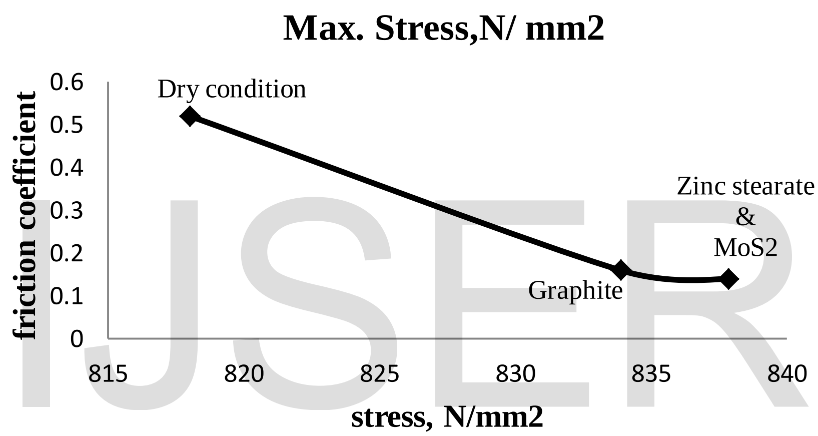
Analytical analysis

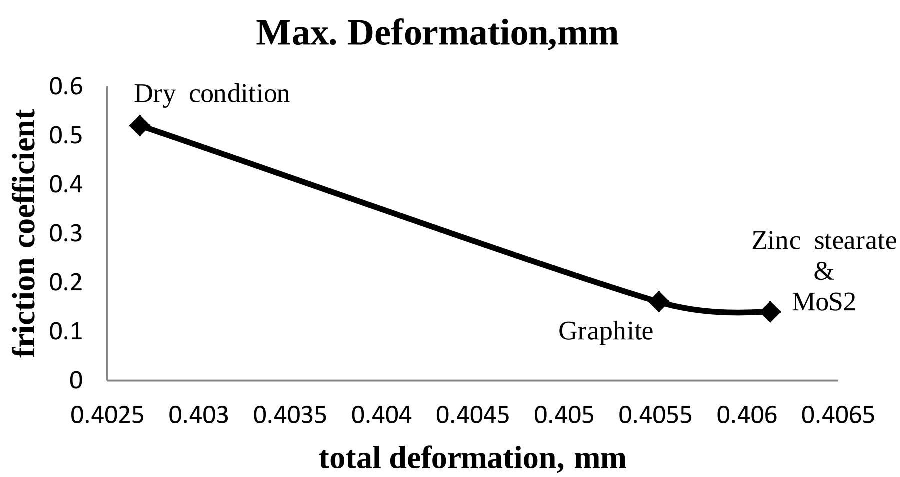
The results of the numerical simulation of the process are highly dependable upon the stipulated boundary conditions of the analysis, especially upon the conditions which define the contact friction. Commercial FEM program packages, intended for 2D or 3D simulation of bulk forming process usually use m-friction model for describing the friction in inter-contact. Through stipulated values of coefficients / factors of friction, the user influences the simulation course and accuracy and applicability of obtained results.

ANSYS 14.0 used to analysis the total deformation and max. Stress depends on different friction coefficient condition.

Lubricant condition	Friction coefficient	total deformation, mm	stress, N/mm2
Dry condition	0.52	0.40268	818.02
Graphite	0.16	0.40552	833.88
MoS2	0.14	0.40613	837.86
Zinc stearate	0.14	0.40613	837.86

The result of this analysis the two contact surface in between the friction value increased the total deformation and max. Stress also reduced. If proper lubricant will apply to reduce the friction value.





6. CONCLUSION

In this research work, I studied about the ring compression test, friction factor, lubrication condition, material properties related to my work.

Friction conditions between die and work piece interface is one of the most important factors in metal forming operations. Ring compression test is an effective method for determining the friction coefficient. The friction coefficient is sensitive to specimen geometry. It decreases with reduction in height and outer radius, and increases with increasing inner radius. This is under both dry and lubricated conditions, also increases with tools surface roughness. This roughness is an essentially important factor in dry forming. This is concluded from the comparison of dry and lubricated conditions. The presence of lubricant at the interface between the tools and work piece reduces the interface friction coefficients. High peak of load tends to appear at the beginning of the forging process but the interface friction is independent to the load applied on the specimen. This is concluded from the rapid decrease in friction coefficients. Lubrication applied is one of most significant factors for it directly determines the interface friction. The calibration curve introduced by Male and Cockcroft can be used to determine the friction coefficients for the ring specimen of specified dimension ratio outer dia.: inner dia.: height as 6: 3: 2. The lubrication applied on the specimen die interface will reduce the inter face friction it can be vary from 0 to 0.577 as by the standards. And the friction facto vary to 0 to 1.

The result of this analysis the two contact surface in between the friction value increased the total deformation and max. Stress also reduced. If proper lubricant will apply to reduce the friction value.

From the experimental, theoretical and analytical analysis the minimum friction obtained is for the Molybdenum disulphide and Zinc stearate and maximum for the dry condition.

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