International Journal of Manufacturing and Materials Processing
Vol. 4: Issue 2
www.journalspub.com

Experimental Study and Analysis of Coefficient of Friction for Mild Steel Under Various Lubrication Conditions

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ABSTRACT

The coefficient of friction plays decisive role in the metal-forming processes. This study focuses on determination of the coefficient of friction between work piece and lubricants using ring compression test by experiments physical modeling and finite element (FE) simulation. A series of ring compression tests were carried out to obtain friction coefficients of mild steel under lubricants including boric acid, Vaseline, grease and dry conditions. According to Male and Cockcroft (1964), the standard geometry (6: 3 :2) was modeled with outer diameter 42 mm, inner diameter 21 mm and height 14 mm. Results show that the coefficient of friction obtained by experimental for dry condition was 0.38, for boric acid was 0.27, for vaseline was 0.22, and for grease was 0.15. The inside diameter of the ring reduces for dry condition, due to high friction and increases for remaining lubricants because of friction-less conditions. The simulation was conducted for the ring compression test using analysis FE software ANSYS. Ring compression test was carried out experimentally and the results were compared with the numerical results and validated. The total deformation and stress variation study is carried out for the inner radius and height of the ring specimen, and friction effect is defined by the deformation profile and stress variation analysis.

Keywords: coefficient of friction, ring compression test, finite element simulation, ANSYS

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INTRODUCTION

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other. Metal working and manufacturing process are affected by friction, because of the relative motion and the force present between tool and work pieces. An excess of friction produces heat, which causes expansion and breakdown of the tool. Friction has effects on the work pieces and process variables such as surface quality, roughness and internal structure of the product so that should be minimized friction between tool and work piece. Friction is reduced by using lubrication between surfaces. Lubricants are used according to the cutting parameter, geometry of the contacting bodies, the roughness and environmental conditions. Friction factor can be used to study the material flow, behavior of material to achieve the desired product with minimum effort, for example, in processes of rolling, extrusion and forging. In view of the frictional conditions of the tool–material interface, its control by using the choice of lubrication depends on the specific application; therefore, in designing a metal-forming operation, it is necessary to minimize friction between metal and tool and evaluate the behavior of metal under various lubrication conditions. A suitable selection of lubrication on metal surface is needed to minimize the friction and smoothness on the contacting surfaces. Different materials with different lubricant results, so different coefficients of friction must be calculated for each different pair of materials and lubricants.

Among all common methods for measuring the friction factor and coefficient of friction, the ring compression test (RCT) has wild acceptance. This technique utilizes the dimensional changes of a test specimen to find out the magnitude of friction of coefficient. Measure reduction of height and the reduction of the internal diameter of the test specimen after compression provide a quantitative knowledge of the magnitude of the friction coefficient at the die/work piece interface. The method of ring compression is a qualitative method for comparing the coefficients of friction conditions of the various materials under lubrication.

LITERATURE VIEW

The previous work was carried out by the researchers in the field of determination of the coefficient of friction using RCT techniques and finite element (FE) method. Robinson et al. [1] investigated the coefficient of friction using the RCT, based on experiments and FE simulation. The outer and inner diameters and height are given as D_0 = 50.8 mm, D_i = 25.4 mm, and H_0=16.9 mm, respectively, and the lubricants Vaseline, zinc stearate and talc powder were used on the surface of the aluminum alloy. The result was showing that the coefficient of friction for Vaseline was less than other lubricants such as zinc stearate and talcum powder.

Sivaprakash et al. [2] studied the friction factor by employing the RCT of aluminum, and materials under different lubrication conditions were applied such as zinc stearate, molybdenum disulfide, and graphite powder and in dry condition. To carry out the RCT, the standard ring specimen ratio of 6:3:2 with outer diameter (42 mm), inner diameter (21 mm) and height (14 mm), respectively. The change in percentage of dimension changes with outer diameter, internal diameter, and height. From this studied minimum friction obtained for the molybdenum disulfide and maximum for the dry condition.

Moncada et al. [3] studied the RCT and considered a reliable way to evaluate the friction factor by using standard calibration. An aluminum material alloy EN AW-2030 is used in this test, and the three geometries are established. These three geometries facilitate different ratios 6:3:2, 6:3:1, 6:3:0.5 between the outer and inner diameters and the height of the specimens under study. The main objective of this paper is to show the applicability of the upper bound theorem in the case of non-symmetrical parts and analysis of plastic deformation of a ring subjected to a process of forge as in case of RCT [3].

Ohdar et al. [4] studied the friction coefficients of different lubricating conditions, viz. graphite in hydraulic oil, graphite in furnace oil and dry condition were obtained from the RCT for the medium carbon micro-alloyed steel (38MnVS6). To carry out the standard RCT, the ratio of outer diameter 45 mm, inner diameter (22.5 mm) and height (15 mm) has been 6:3:2. Results of this RCTs indicate that the coefficient of friction (μ) is the lowest in the alloy steel with hydraulic oil + graphite condition and the highest for dry condition.

Christiansen et al. [5] studied a combined numerical and experimental methodology for determining three different friction models based on Coulomb friction, the constant friction model or combined friction models are utilized. Experimental results obtained from aluminum cylindrical test specimens with different lubricants Molykote paste and Teflon powder combined with the experimental determination of friction by means of RCTs allow compensating the effect of friction in the determination of the material flow curve. The friction coefficient is less in Teflon sheets, which is 0.26.

MATERIAL AND METHODS

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 specimen dimensions when subjected to compression. The reduction in height, increase or decrease of the internal diameter, and external diameter determine the coefficient of friction under various lubrication conditions.

Specimen Material and Dimensions

Mild steel was selected as the material. The specimens were machined to the sizes of outer diameter, inner diameter and height ratio of 6:3:2 [6]. The mild steel rod of 45 mm diameter was machined to the required outer diameter of 42 mm, inner diameter 21 mm, and height of 14 mm by using lathe machine as show in Figure 1.

Fig. 1. *Specimens dimension used in experiment.*

Ring Compression Test

A series of RCTs were conducted by CTM (compression testing machine) on mild steel ring specimen for each condition of lubrication. In the present work, the lubricants used were boric acid, Vaseline and grease. Ring specimens were compressed to within different loads range (1000–1400 kN). In the present study, the friction calibration curves were constructed and the deformation behavior of the geometry of the ring specimen was examined. This method has the advantage of determining friction coefficient based on the dimensional changes of the geometry of ring specimen. The requirements of experimental setup were compression testing machine and digital vernier caliper.

Compression Testing Machine (CTM)

CTM is designed to test materials and other materials under compression, bending, transverse and shear loads. RCT was conducted on mild steel using CTM which show in Figure 2. The features of CTM are as follows:

- The CTM design features to enable high accuracy testing with economy, speed and versatility.
- High reading accuracy due to LCD display and maximum capacity of 2000 kN.
- Wide range of standard and special accessories, including load stabilizer.
- Large effective clearance between columns enables the testing of standard specimens as well as structures.

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, environment temperature and humidity were all kept at constant values.

Fig. 2. *Compression testing machine.*

The process of experiment was carried out by changing the different lubricants (boric acid, grease, Vaseline) and load (1000–1400 kN) to determine the coefficient of friction. The initial dimensions of the ring are in the following ratio: outer diameter: inner diameter: height = 6:3:2, which were adopted as standard dimensions in ring test method. Dimensions were taken as outer diameter 42 mm, inner diameter 21 mm, and height 14 mm. In this test, a ring specimen is compressed between the flat parallel plates of mild steel, and the coefficient of friction is determined on the basis of the change in the dimension of specimen. Specimen is freely placed on the lower die in a way that centre lines of both coincided, which is shown in Figure 3. The CTM is then started, pressing the specimen at a constant speed. After compressing, remove the specimen and the new inner diameter, outer diameter and thickness were measured by using digital vernier caliper. After compression, the dimension of the specimen changes as shown in Figure 4. However, due to barreling and irregularity on both inner and outer cylindrical surfaces of specimen, several diametric readings were taken and the average was recorded. Now we have the compressed specimen with different load. In addition to the above steps, the specimen and die-contacting surfaces were lubricated before compression using different lubricants like grease, boric acid and Vaseline. Apply lubrication at upper and bottom surfaces of work piece and apply a different load condition. After each and every stage of the deformation process, dimensions were measured using digital vernier caliper. In Figure 5, the ring specimens are shown after the compression process.

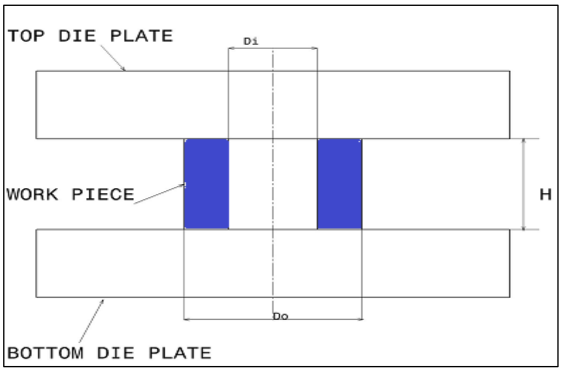


Fig. 3*. Specimen before compression.*

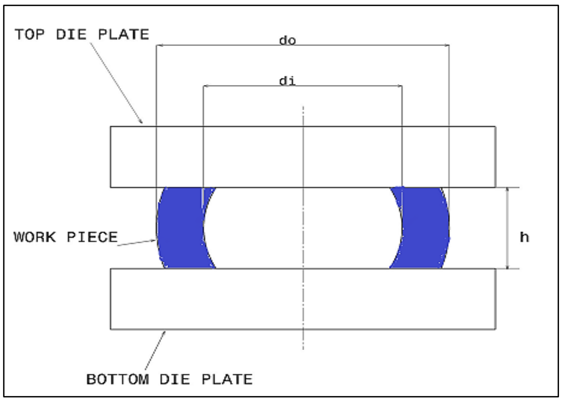


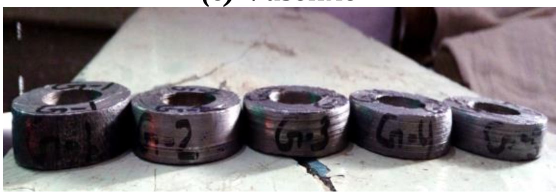
Fig. 4. *Specimen after compression.*

Note: D_i = Outer diameter before deformation (mm); D_o = Inner diameter before deformation (mm); H = Height before deformation (mm); d_o = Outer diameter after deformation (mm); d_i = Inner diameter after deformation (mm); h = Height after deformation (mm).

(a) Dry condition

(b) Boric acid

(c) Vaseline



(d) Grease

(e) Specimens after deformation

Fig. 5. *Specimens after deformations at different load and lubrication condition.*

The dimensions of the specimen were measured after deformation, and substituted in Equations (1)–(3) [7]:

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

$$Rn = Ro\sqrt{\frac{\left(\frac{Ri}{Ro}+\frac{\Delta Ri}{\Delta Ro}\right)}{\left(\frac{Ro}{Ri}+\frac{\Delta Ri}{\Delta Ro}\right)}} \quad (2)$$

$$\mu = \frac{m}{\sqrt{3}} \quad (3)$$

where R_i is the inner radius of specimen after deformation; R_o is the external radius of the specimen after deformation; ΔR_o is the change in outer radius of the specimen after deformation; ΔR_i is the change in internal radius of the specimen after deformation; R_n is the mean radius of the specimen after deformation; h is the height of the specimen after deformation; m is the friction factor; and μ is the coefficient of friction.

The variation in change in inner diameter and the height reduction in percentage (ΔID% and ΔH%, respectively) were calculated as follows:

$$\Delta ID\% = \frac{Di-di}{Di} \times 100\% \quad (4)$$

$$\Delta H\% = \frac{H-h}{H} \times 100\% \quad (5)$$

Finite Element Method

In this study, RCT is considered and it has been ensured that deformations are made for materials depending on the coefficient of friction between work piece and die. The simulations were conducted for the mild steel and were simulated using static analysis FE code (ANSYS workbench). For different loads and friction coefficients is provided analysis FE code (ANSYS workbench). For different load and coefficients of friction are provided for simulation, the profile changes for inner surface node are investigated.

RESULT AND DISCUSSIONS

Experimental Determination of Coefficient of Friction

RCTs were performed on mild steel. The tests were conducted using the ring geometry ratio of 6:3:2 [6] with the actual physical dimensions of the ring being 42 mm outer diameter, 21 mm inner diameter, and 14 mm height (thickness). The tests were performed under room temperature of 25°C using three lubricants as boric acid, Vaseline and grease to study the coefficient of friction and the performance of the lubricants. The dimensions of specimen after compression were measured using digital vernier caliper. However, due to barreling and irregularity on both inner and outer cylindrical surfaces of specimen, five readings were taken and an average value was recorded and Avitzur [7] equations were used to determine the coefficient of friction. After the calculation, the results show that the average coefficient of friction for the dry condition, boric acid, Vaseline, grease were 0.38, 0.27, 0.22 and 0.15, respectively. The friction calibration curves obtained for mild steel for different friction conditions between height reduction and inner diameter reduction are obtained shown in Figure 6(a–d). For dry condition, the inner diameter reduction percentage was positive because the inner diameter after compression was decreased, i.e. less than actual inner diameter 21.0 mm shown in Figure 6(a), but for other lubricants, the inner diameter reduction percentage was negative because the inner diameter after compression was increasing, i.e. more than the actual inner diameter 21.0 mm; and Figure 6(b–d) shows that friction calibration curve for boric acid, Vaseline and grease, respectively.

From the result, we conclude that, for dry condition (μ = 0.38), the flow of metal is inward, and as the friction coefficient reduces, the metal flow becomes outward. The combined friction calibration curve for the friction condition is shown in Figure 7.

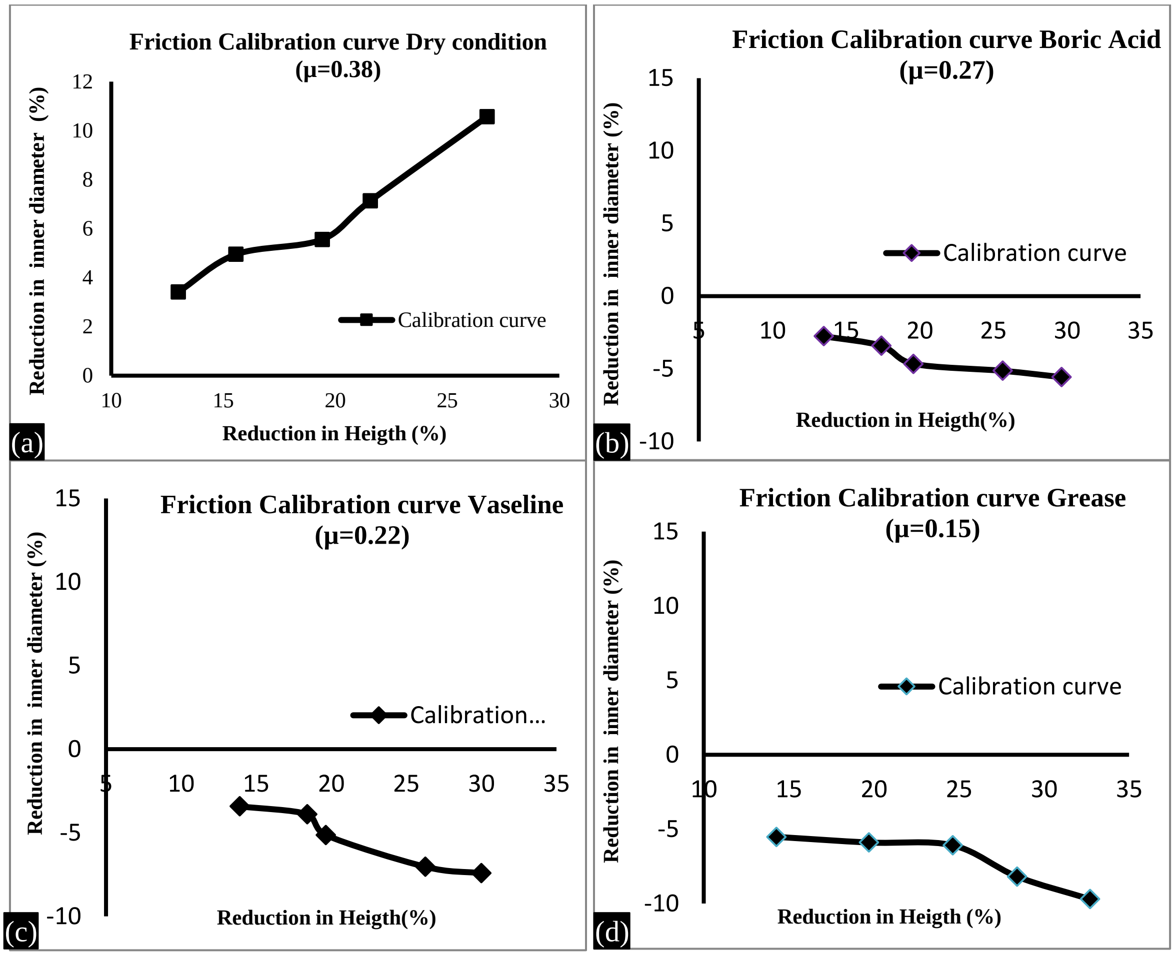


Fig. 6. *Experimental friction calibration curve for (a) μ = 0.38 (b) μ = 0.27 (c) μ = 0.22, (d) μ = 0.15.*

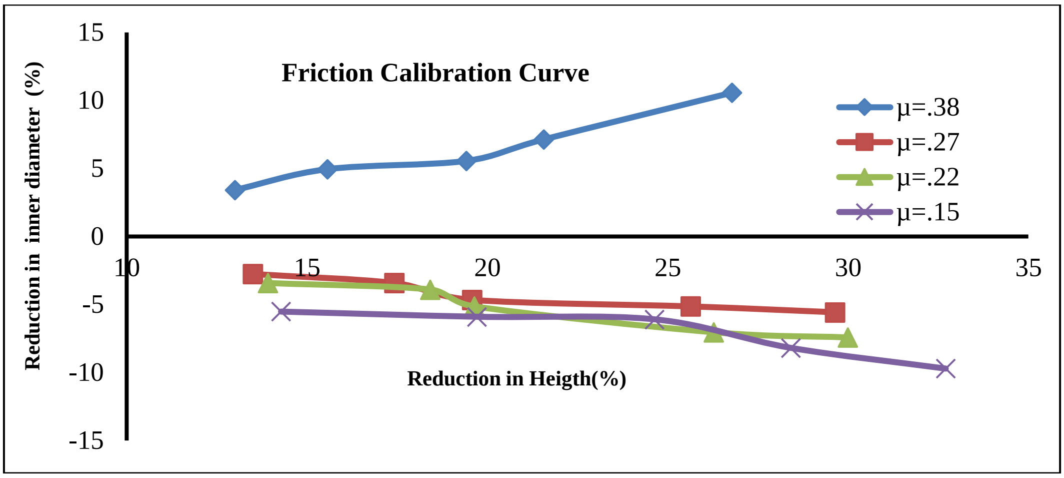
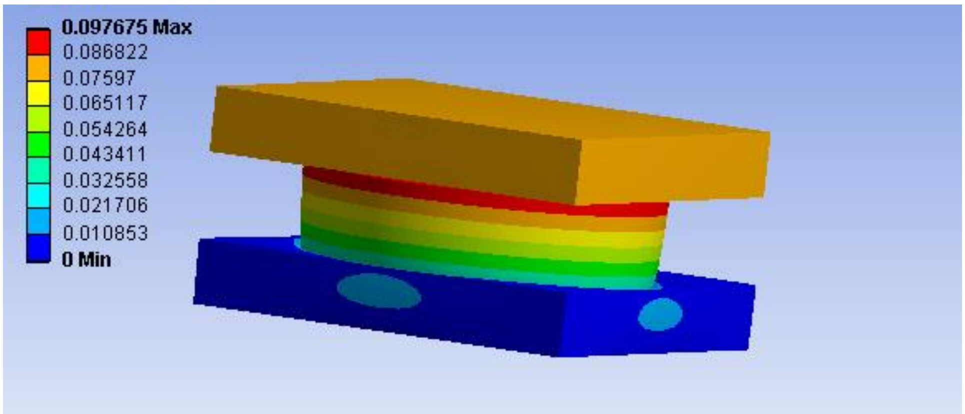
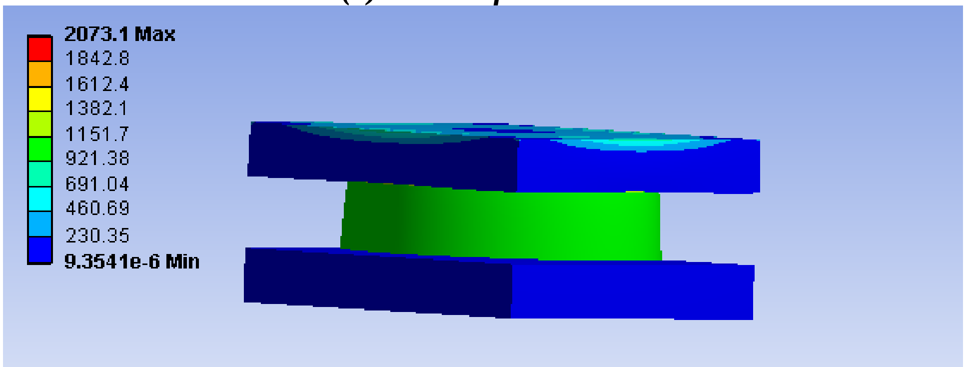


Fig. 7. *Combine friction calibration curve for mild steel.*



(a) Total deformation



(b) Stress Analysis

Fig. 8. *Finite element analysis of ring compression test.*

Finite Element Analysis

Coefficient of friction for different lubrications was determined by experimental, and this value was used in the FE method, using FE software ANSYS. The solution obtained by the solution process is a general solution. The total deformation and stress plot are obtained for the particular load condition and coefficient of friction, represented in Figure 8(a, b), respectively.

Comparison Study Between Experimental and Finite Element Method

In an attempt to determine the frictional calibration curves under various lubrication conditions, ANSYS FE code was employed in the simulation of simple compression of a cylindrical ring, with 42 mm outside diameter, 21 mm inside diameter, and 14 mm height. Due to the axis symmetric nature of this problem as well as the existence of two axes of symmetry within each plane, a 2-D model representing of the cylindrical ring was constructed and the result was obtained by FE analysis. From experimental determination of percentage reduction, the inner diameter and height were compared with the FE method result.

Figure 9 shows the comparison between friction calibration curves obtained from FE method and experimental for μ = 0.38 (dry condition), μ = 0.27 (boric acid), μ = 0.22 (Vaseline) and μ = 0.15 (grease). It can be explicitly seen from these figures that some variation between experimental and FEM result because of environmental condition and some other manual error in experimental test. But both results were showing approximately the same graph, i.e. the results show that if the specimen's internal diameter increases during the deformation, the reduction in inner diameter was negative and the coefficient friction was low; and if the specimen's internal diameter decreases during the deformation, the reduction in inner diameter was positive and the coefficient friction is high.

In fact, this FEM technique is not only the simulation of the compression process but also the prototype of the actual metal compression process. It can, therefore, be seen that this FEM technique would be more applicable than the RCT for determining the deformation of specimen due to particular coefficient of friction in metal-forming processes.

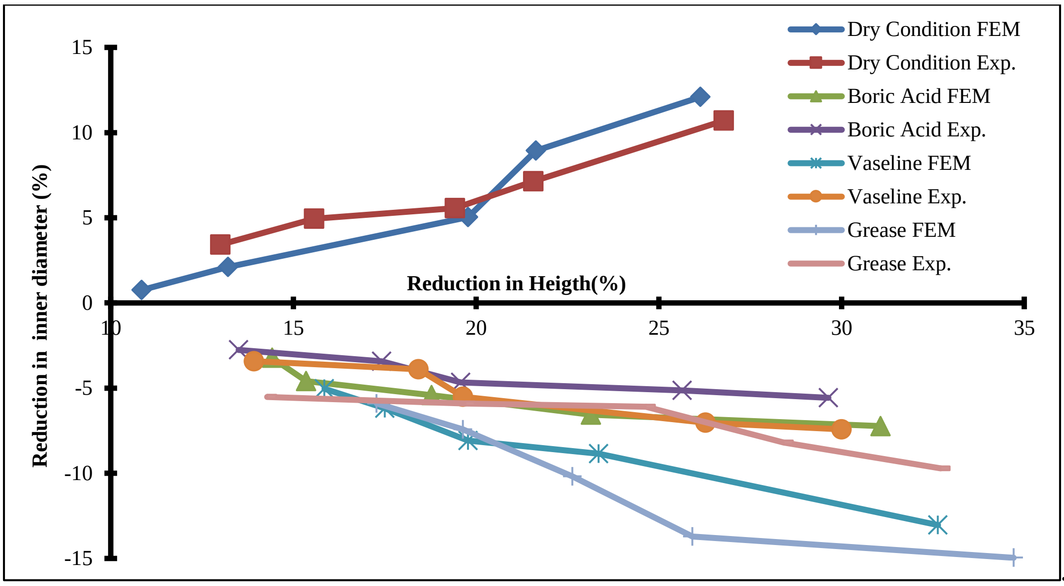


Fig. 9. *Friction calibration curve for mild steel obtained from FEM and experimental analysis.*

CONCLUSIONS

In this research work, the RCT, friction coefficient, lubrication condition and material properties are studied related to our work. Friction conditions between die and work piece interface is one of the most important factors in metal-forming operations. RCT is an effective method for determining the friction coefficient.

- The coefficient of friction value for the ring specimen of specified dimension ratio – outer diameter: inner diameter: height as 6:3:2 – obtained experimentally for dry condition is

0.38, for boric acid is 0.27, for Vaseline is 0.22 and for grease is 0.15.

- Vaseline, boric acid and dry conditions as earlier. In dry conditions, the friction factor is more when compared with lubricated condition under various load conditions.
- The result of this analysis of the two contact surfaces in between the friction value increased the total deformation and reduced the stress.
- The results obtained experimentally and numerically are compared and the friction curve is validated. The friction curve is more useful for analysing the material behaviour on forging process and selecting the lubricant for the process. This friction calibration curve is valid for mild steel material only. As lubrication changes, then the coefficients of friction value also vary according to the lubricant.
- Using this friction curves, we can predict the lubricant for forging or extrusion process and the deformation profiles are analyzed to reduce unwanted machining.
- The deformation and stress variation study is carried out for the inner radius of the ring and barrelling effect is defined by the deformation profile and stress analysis. These analyses are useful for the material flow and profile variations for different lubrication.
- Grease acts as an efficient lubricant in various load conditions followed by

REFERENCES

[1] Robinson T, Armstrong CG. Study on ring compression test physical modelling and FE simulation. *J Mater Proc Technol.* 2004; 153: 54–59p.

[2] Sivaprakash M, Emmanuel R. Analysis of friction factor by employing the ring compression test under different lubricants. *Int J Sci Eng Res.* 2013; 4: 1163–1171p.

[3] Moncada A, Martín F, Sevilla L, Camacho AM, Sebastián MA. Analysis of ring compression test by upper bound theorem as special case of non-symmetric part. *Proc Eng.* 2015; 132: 334–341p.

[4] Ohdar RK, Talukdar P, Equbal M. Evaluation of friction coefficient of 38MnVS6 medium carbon micro-alloyed steel in hot forging process by using ring compression test. *Technol Lett.* 2015; 2(3): 12–16p.

[5] Christiansen P, Martins PAF, Bay N. Friction compensation in the upsetting of cylindrical test specimens. *Int J Adv Manuf Technol.* 2016; 56: 1271–1279p.

[6] Male AT, Cockcroft MG. A method for the determination of the coefficient of friction of metals under conditions of bulk plastic deformation. *J Inst Met*. 1964; 93: 38–46p.

[7] Avitzur B. Metal forming. Processes and Analysis. Mcgraw-Hill, Inc., New York. 1968; 500p.