Available online at www.pelagiaresearchlibrary.com

Pelagia Research Library

Pelagia Research Library

Advances in Applied Science Research, 2011, 2 (5): 279-289

Advances in Applied Science Research

Pelagia Research Library

ISSN: 0976-8610
CODEN (USA): AASRFC

Friction calibration map for determination of equal frictional conditions

Ajay Kumar Kaviti, Om Prakash and P. Vishwanath

Sagar Institute of Science and Technology, Gandhi Nagar, Bhopal, India

---

ABSTRACT

In the metal forming process, a realistic frictional condition must be specified at the die/work piece interface in order to obtain accurate metal flow. Several methods are developed to evaluate friction in large deformation processes. This paper presents the concept of friction calibration map to determine different frictional conditions between interfaces of die and billet in the upsetting process. These maps are generated based on the finite element simulation studies. Three such maps are generated for aluminum for three aspect ratios. Numerical and experimental verification of these maps also attempted to show the accuracy of these maps.

Key-word: Metal; Barreling; Friction; Calibration; Finite element.

INTRODUCTION

The main objective of metal forming process is to produce desired shape of final product at reduced cost. Friction plays vital role in all metal working process because of its direct interaction between die and work piece. Friction is predominantly the effect of the high pressures used and surface roughnesses in both die and work piece interface. The unavoidable friction obstructs free movement at interfaces and further it significantly affects the flow and deformation of the work piece. Thus prediction of coefficient of friction between the die and the billet interface become important, in order to avoid the need for secondary processing to remove small amounts of billet materials by machining and to reduce defects due to improper material flow. The coefficient of friction is usually determined either by experimental methods or by simulation using specimens of various shapes. There are several tests, reported in literature, to evaluate friction. Most popular among them is the Ring Compression Test. It was proposed by Kunogi [1] and later improved by Male and Cockcroft [2].

The analysis of Avitzur [3] formed the bases for most of the subsequent work on ring compression test. Liu [4] characterized interfacial friction in axisymertic upsetting of rings using a constant coefficient friction. Lee et. al. [5] used an alternative approach of describing friction

using interfacial zone of material of constant shear strength and friction factor model for upsetting of cylinders and rings. Hasan Sofuoglu et al [6] used the ring compression test to measure coefficient of friction. Sofuoglu et al. [7] developed a new technique, namely, the open-die backward extrusion test technique (ODBET) as an alternative method to the ring compression test in order to quantitatively evaluate the coefficient of friction, at the die and work piece interface. Robinson et al [8] studied Ring compression test using physical modeling and FE simulation. Bhattacharyya et al [9] tested aluminium and copper materials to determine the values of interfacial friction. Schey et al [10] identified the effect of friction on pressure in upsetting considering different geometries of cylindrical billet. Carter and Lee [11] characterized interfacial friction in axisymmetric upsetting using a constant coefficient of friction Venugopal et al [12] determined the friction factor by means of Reduced Capacity Test. Forcellese et al [13] evaluated friction in cold metal forming. Li et al [14] reported that friction is mainly due to surface roughness in both die and work piece and high pressures and it can be reduced by lubrication. Hayhurst et al [15] used two-parameter friction model is used which for the calibration of friction models for metallic die–work piece interface. Danuta Szeliga et al [16] presented an application of the inverse analysis to the identification of friction in metal forming. Pradeep et al [17] studied the effect of surface structures of hard surfaces on coefficient of friction. Pradeep et al [18] studied the effect of surface roughness and surface texture on friction.
It can be observed that most of the above literature address the measurement of friction considering the same surface roughness between the top die and work piece and in between the bottom die and work piece. In actual conditions there may exist different roughness indicating different frictional conditions at top and bottom surfaces. In order to evaluate these conditions, a new approach named as friction calibration map (FCM) is proposed. These maps are generated using the FE simulation results of the billet upsetting. Friction calibration maps for commercial aluminum and mild steel are generated. Numerical validations of these maps are successfully attempted for newer frictional conditions. It is found that the proposed approach provides a simple and reliable determination of the frictional conditions.

MATERIALS AND METHODS

In Fig.1, schematic diagrams of undeformed and deformed billets are shown. Let d_o and h_o are the initial diameter and height of the cylindrical billets, considered for upsetting. In Fig.1(b), die and work piece interface is considered as frictionless. Thus there is large homogeneous deformation in the diameter. In Fig.1(c) friction is considered between die and work piece interface. There is inhomogeneous deformation with barreling of work piece. Let top, middle and bottom diameters of deformed billets are D_1, D_2, D_3 respectively. The middle and bottom diameter ratios of the deformed billet with respect of top diameter can be expressed as $R_1=D_1/D_3$, $R_2=D_2/D_1$. These ratios largely depend on interface frictional conditions. Different sets of interfacial frictional conditions are considered in this study. Finite element simulations of these cases are carried out to obtain the deformation behavior. Based on simulation results, friction calibration maps are developed to predict friction values at die and work piece interfaces.

Geometrical, material and processing parameters

Cylindrical specimen of 40 mm top and bottom diameters and 40 mm height are used for simulation studies and to develop friction calibration maps. Billets are considered to be made of commercial aluminum and mild steel. Material modeling has been carried out using the power law equation [19]:

$$\sigma = K.\varepsilon^n$$

Where K is the strength coefficient and n is the hardening exponent.

The values of K and n considered for aluminum are 225.4 MPa and 0.25. Nine values of Coulomb's friction 'f', viz.0.05, 0.075, 0.1, 0.125, 0.15, 0.175, 0.2, 0.225, 0.25, 0.275 and 0.3 are accounted in the simulation studies. Eleven combinations of interfacial frictions at top and bottom surfaces of billet and dies, considered for simulation studies, are given in Table1.

FE Simulation

Finite element analyses of the upsetting process are carried out using MSC.Marc software [20]. Taking advantage of the symmetrical conditions, axisymmetrical formulation is adopted. Four nodded quadrilateral elements are used for the FE modeling. There are 800 elements and 861 nodes in the model shown in Fig.2. The contact between the billet and the platen is modeled via contact option of the software. The billet is modeled deformable body, while punch and die are modeled as rigid bodies. Bottom die is fixed whereas punch is movable by giving the displacement boundary condition. Considering the various possible friction conditions that can exist at die and billet interfaces (Table 1), eleven cases are simulated. Billets are identically deformed to the final height of 28 mm viz. 30 % reduction in height for each case. Typical FE deformed mesh for different frictional conditions are shown in Fig.3. Diameter ratios R_1 & R_2 of the final deformed geometry of billet are noted for the map generation purpose.

Development of friction calibration maps

To simplify the determination of friction values at top and bottom interfaces between platen and billet, friction calibration map (FCM) is generated. This is the contour map of $R_{1,}$ R_2 values with respect to f_t and f_b. Here f_t is friction at top and f_b at bottom interface. Using the simulation results, friction calibration curves for commercial aluminum and are generated as shown in Fig 4, In this figure solid and broken line represent f_t and f_b respectively. Software SURFER software [21] has been employed for this purpose. These calibration maps can be used as a means of determining the frictional conditions using the deformed geometry data.

Experimental Validation

The following experimental verification of the proposed generalized Friction Calibration Map is carried out based on the upsetting experiment of aluminum ring and aluminium specimens of size 40 mm diameter and with 40 mm height. These experiments are performed on compression testing machine. The first step is to determine friction between top and bottom surface of the compression testing machine and the specimen interfaces. Friction determination is carried out using standard ring compression test.

Ring compression test for aluminum ring

The experiment was conducted using standard dimension rings of commercial aluminum of outer and inner diameters of 40 mm and 20 mm and height of 13.33 mm (OD:ID:H = 6:3:2). These rings were subjected to compression in a standard compression Testing Machine using case hardened steel platens. A maximum load of 500 KN was applied and the rings were compressed in 2-3 stages, with a 2 mm displacement of the top platen at each stage. Lubricants were not applied to the top, bottom and lateral faces of the ring specimen after each stage of compression. The specimens, after each stage of compression were cleaned and for the next stage of compression. Figure 5 shows the specimens that were used for experimentation and specimen after deformation. It was observed 30% reduction in height and 11.7 % reduction in internal diameter. These percentage reductions are compared with the Friction Calibration Curves (Sofuoglu, 1999) and coefficient of friction μ (Coulomb) is obtained as 0.17. The experimental data of aluminium ring of internal diameter 20 mm, external diameter 40 mm and height 13.33 mm for ring compression test is shown in Table 2.

Compression of aluminium billet of 40 mm diameter and 30 mm height

An aluminum billet of 40 mm diameter and height of 30 mm is used for the compression test. This billet was subjected to compression in a standard compression Testing Machine using case hardened steel platens. A maximum load of 625 KN was applied and this billet was compressed in 4-5 stages, with a 2 mm displacement of the top platen at each stage. The specimen, after each stage of compression was cleaned and for the next stage of compression. Figure 6 shows the specimens that were used for experimentation and specimen after deformation. It was observed 30 % reduction in height (i.e. 9 mm) and dimensions of deformed billet top, middle and bottom diameters are 45.6 mm, 48.3 mm and 45.6 mm respectively. Figure 6 shows the billets before and after deformation and the Table 3 and 4 shown the dimensions before and after deformation.

Compression of aluminium billet of 40 mm diameter and 40 mm height

An aluminum billet of 40 mm diameter and height of 40 mm is used for the compression test. This billet was subjected to compression in a standard compression Testing Machine using case hardened steel platens. A maximum load of 600 KN was applied and this billet was compressed in 4-5 stages, with a 2 mm displacement of the top platen at each stage. The specimen, after each stage of compression was cleaned and for the next stage of compression. Figure 6 shows the specimens that were used for experimentation and specimen after deformation. It was observed 30 % reduction in height (i.e. 12 mm) and dimensions of deformed billet top, middle and bottom diameters are 45.4 mm, 49.1 mm and 45.4 mm respectively. Figure 7 shows the billets before and after deformation and the Table 3 and 4shown the dimensions before and after deformation.

Compression of aluminium billet of 40 mm diameter and 50 mm height

An aluminum billet of 40 mm diameter and height of 50 mm is used for the compression test. This billet was subjected to compression in a standard compression Testing Machine using case hardened steel platens. A maximum load of 550 KN was applied and this billet was compressed in 4-5 stages, with a 2 mm displacement of the top platen at each stage. The specimen, after each stage of compression was cleaned and for the next stage of compression. Figure 8 shows the specimens that were used for experimentation and specimen after deformation. It was observed 30 % reduction in height (i.e. 15 mm) and dimensions of deformed billet top, middle and bottom diameters are 45 mm, 50 mm and 45 mm respectively. Figure 8 shows the billets before and after deformation and the Table 3 and 4 shown the dimensions before and after deformation.

Numerical Validation

Several examples are presented to show the efficacy of the friction calibration maps on aluminum and mild steel upsetting. Cylindrical billet of 40 mm diameter and 40 mm height is simulated by considering newer interface frictions as given in the Table 4. For each case deformed diameter ratios (R_1 & R_2) are noted from the simulation results. These values are superimposed on the friction calibration maps to identify the friction values. These values are also given in the Table 3. Comparison of actual friction values with that obtained from the map are made and both are found to be in close match. This shows that friction calibration map can be effectively used to obtain coefficient of friction between tool and work piece interfaces.

Table 1: Friction conditions at die and billet interface

S.No.	μ_t	μ_b
1	0.05	0.05
2	0.075	0.075
3	0.1	0.1
4	0.125	0.125
5	0.15	0.15
6	0.175	0.175
7	0.2	0.2
8	0.225	0.225
9	0.25	0.25
10	0.275	0.275
11	0.3	0.3

Table 2 Experimental data of ring compression test

S.No.	Surface	Final ID	Final OD	Final Height	% reduction in ID	% reduction in Height	μ
1	DRY-DRY	17.66	44.6	9.3	11.7	30	0.17
2	WET-WET	19.2	44.4	9.24	3.92	30	0.09

Table 3 Experimental data of Billet for WET- WET condition

S. No.	Size	D1	D2	D3	H	R1=(D1/D3)	R2=(D2/D1)
1	30	48	45.2	45.2	21	1.061946903	0.941666667
2	40	48.5	46.1	46.1	28	1.052060738	0.950515464
3	50	49.41	46.4	46.4	35	1.06487069	0.939081158

Table 4 Experimental data of Billet for dry dry condition

S. no.	Size	D1	D2	D3	H	R1=(D1/D3)	R2=(D2/D1)
1	30	48.3	45.6	45.6	21	1.059210526	0.944099379
2	40	49.1	45.4	45.4	28	1.081497797	0.924643585
3	50	50	45	45	45	1.111111111	0.9

Table 5: Comparison of coefficient of frictions for aluminum

S.No.	Height of the Billet (mm)	$R_1 = D_1/D_3$	$R_2 = D_2/D_1$	Interface friction μ		
				Actual	FCM	% error
1	30 (Dry)	1.059210526	0.944099379	0.17	0.16	0.064
	30 (Wet)	1.061946903	0.941666667	0.06	0.066	0.1
2	40 (Dry)	1.081497797	0.924643585	0.17	0.153	0.1
	40 (Wet)	1.052060738	0.950515464	0.06	0.171	0.64
3	50 (Dry)	1.111111111	0.9	0.17	0.198	0.164
	50 (Wet)	1.06487069	0.939081158	0.06	0.052	0.13

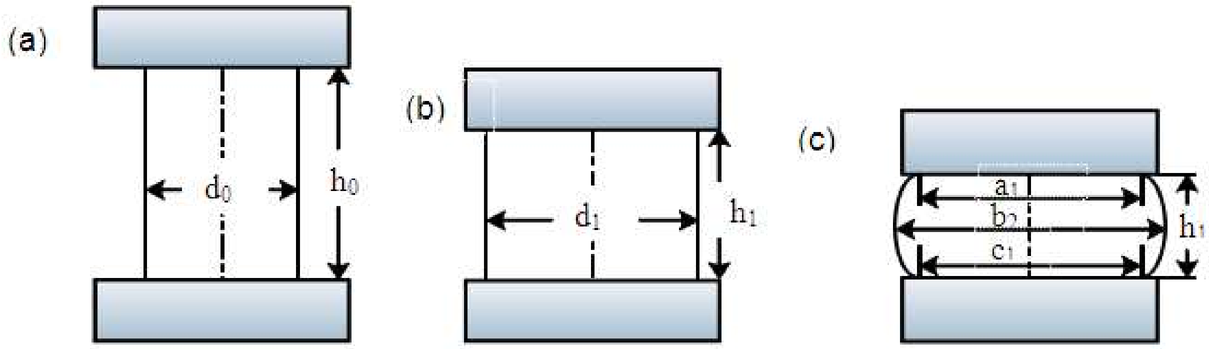


Figure 1: (a) Undeformed Figure condition of billet
(b) Deformed condition of billet under ideal condition
(c) Deformed condition of billet under frictional condition

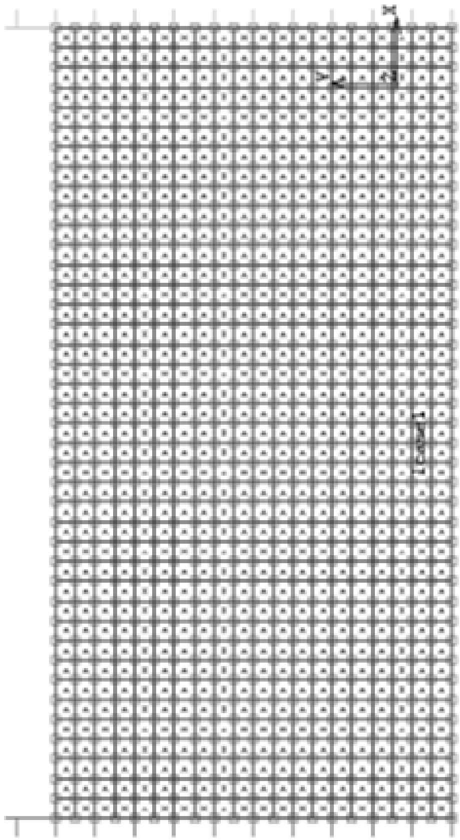


Fig 2 FE model of the undeformed billet

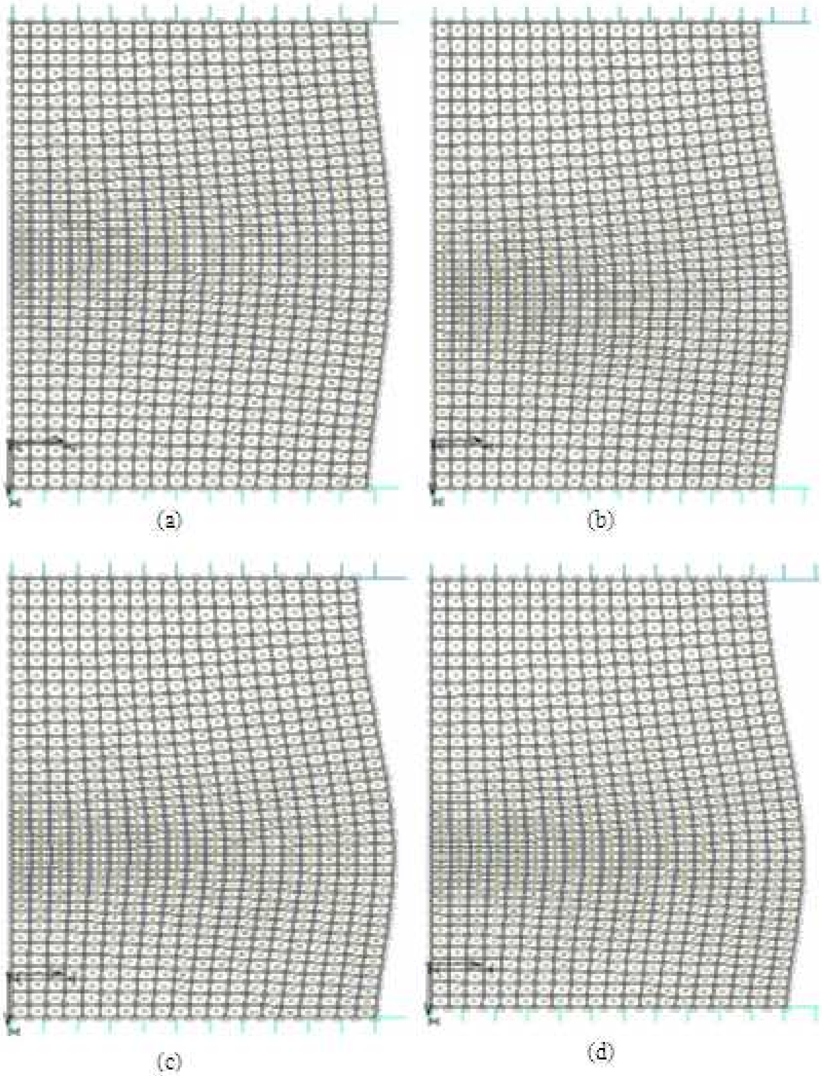


Fig 3 Deformed FE mesh for different frictional conditions (a) f_t =0.1, f_b =0.1 (b) f_t =0.2, f_b =0.15 (c) f_t =0.3, f_b =0.25 (d) f_t =0.4, f_b =0.35

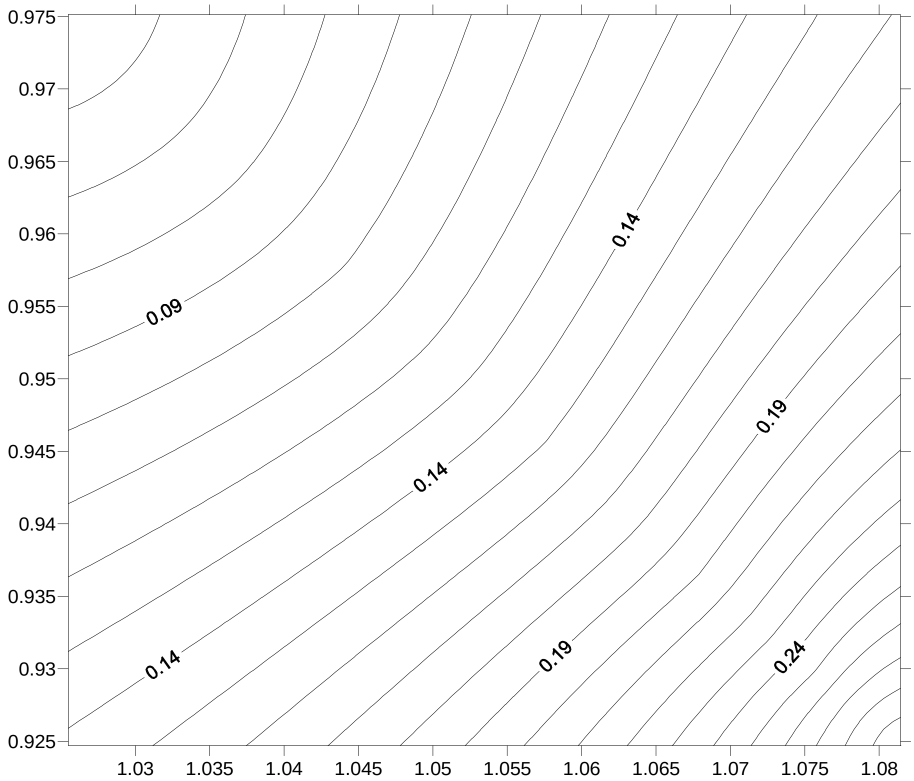


Figure 4. Friction calibration map of 30 mm aluminium

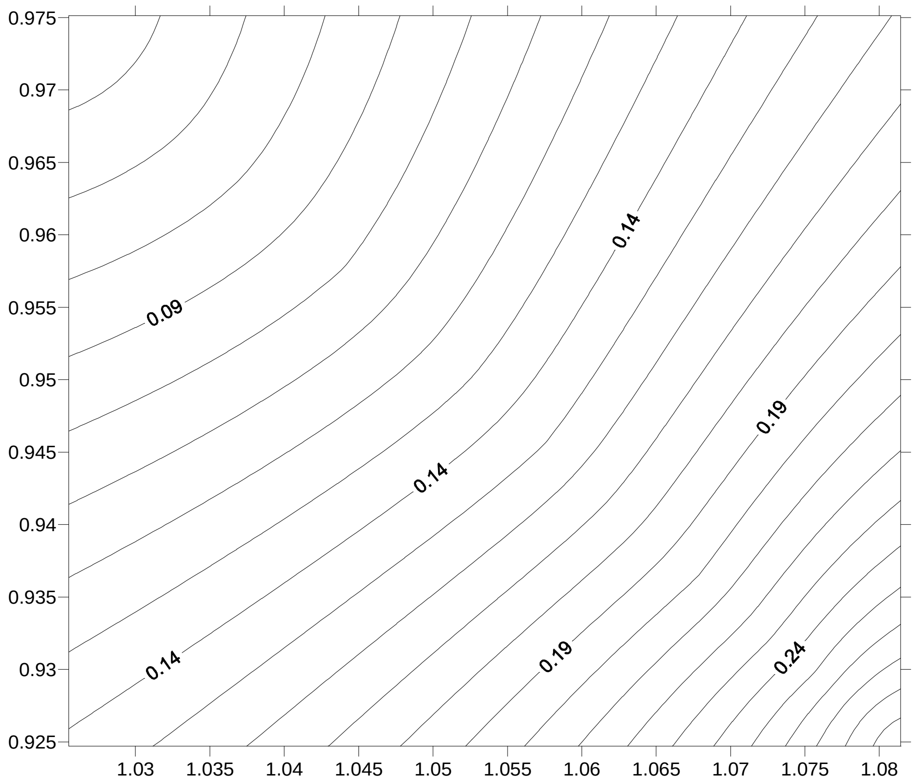


Figure 5 : Friction calibration map of 40 mm aluminium

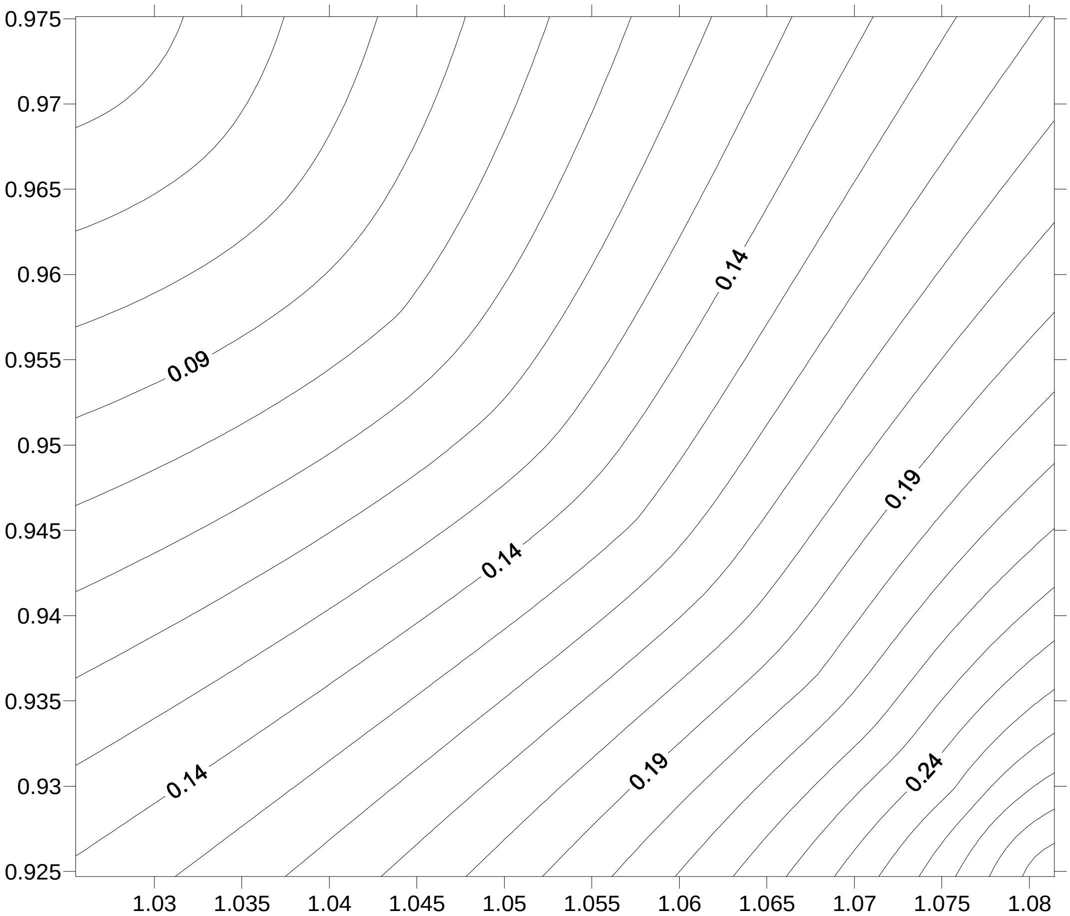


Figure 6 : Friction calibration map of 50 mm aluminium work piece

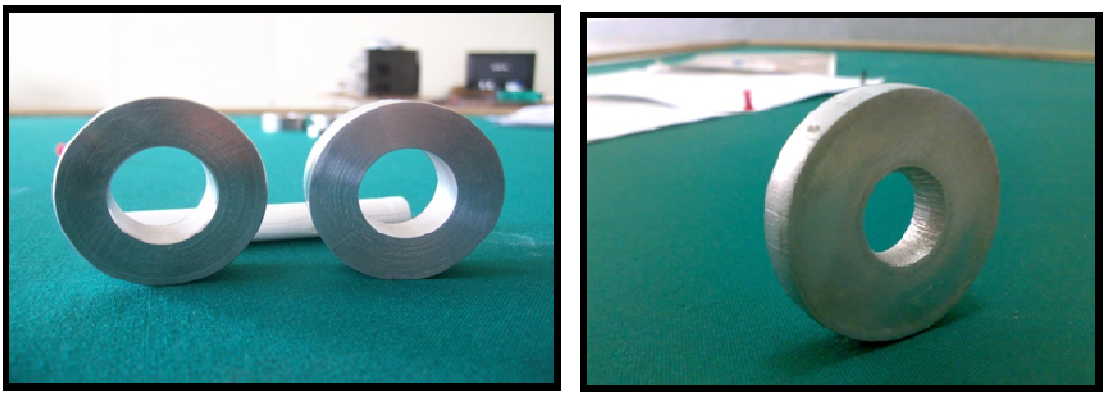
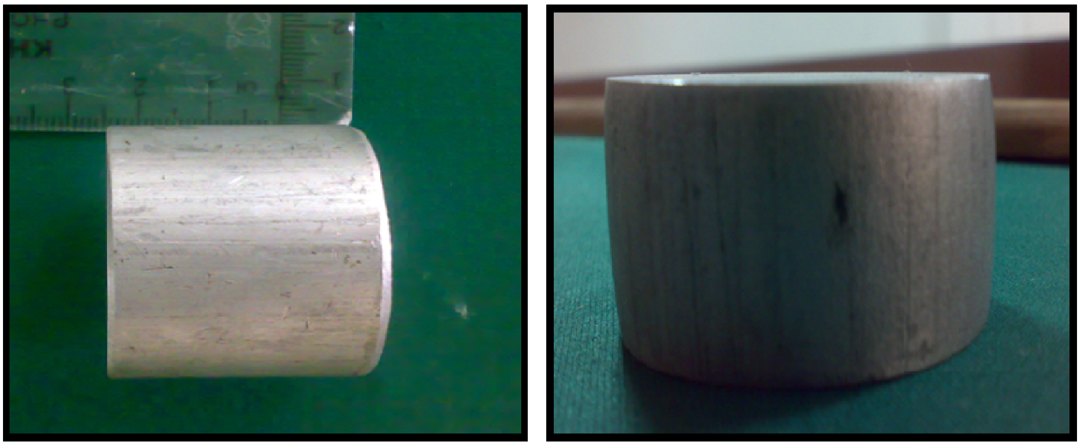
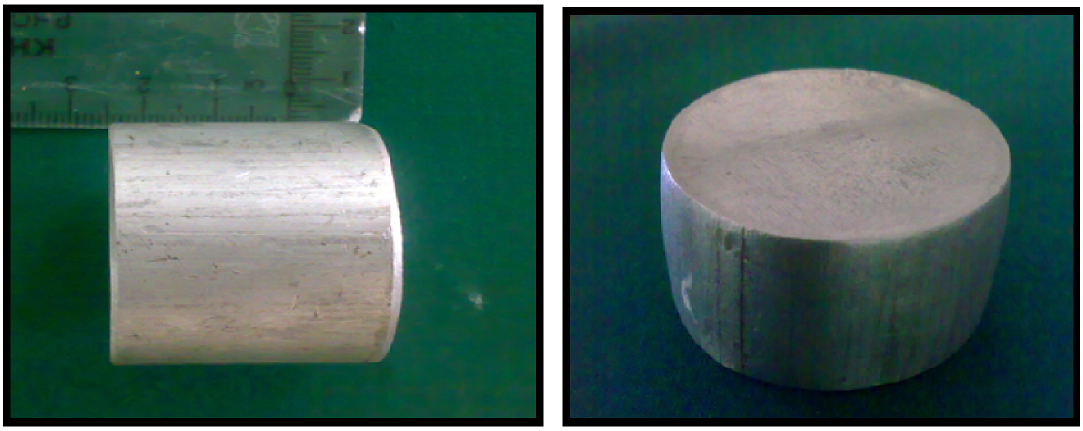


Figure 7 (a) Aluminum ring before compression
(b) Aluminum ring after compression



(a) (b)

Figure 8 (a) Aluminium billet of height 30 mm diameter 40 mm before compression
(b) Aluminium billet of height 30 mm diameter 40 mm after compression



(a) (b)

Figure 9 (a) Aluminum billet of size height 40 mm dia.40 mm before compression
(b) Aluminum billet of size height 40 mm dia.40 mm after compression

(a) (b)

Figure 10 (a) Aluminium billet of height 50 mm diameter 40 mm before compression
(b) Aluminium billet of height 50 mm diameter 40 mm after compression

CONCLUSION

Friction conditions between die and work piece interface is one of the most important factors in metal forming operations. Although, ring compression test is an effective method for determining the friction coefficient, it can't be used for unequal friction conditions. In this regard the proposed approach of friction calibration map (FCM) offers a powerful solution for determination of unequal interfacial frictions. Numerical validation of the FCM on aluminum & mild steel specimens are very close to the actual. It is hoped that this will be a very helpful tool to the design engineers involved in metal forming process design.

REFERENCES

[1] Kunogi MA *J.Sci.Res.Inst*. (Tokyo),50, (**1956**), 215.

[2] Male AT, *J Inst Metals*,93, (**1964**), 38–46.

[3] Avitzur B, *Journal of Engineering for Industry-Transactions of the ASME,* (**1972**), 1149.

[4] Lee C.H., Altan T. *Journal of Engineering for Industry-Transactions of the ASME,* (**1972**), 775.

[5] Hasan Sofuoglu, Jahan Rasty. *Tribology International*, 32, (**1999**), 327.

[6] Sofuoglu H, Gedikli H. *Tribology International*, 35, (**2002**), 27.

[7] Robinson T, Ou H, and Armstrong, C. G . *J. Mater. Process. Technol*., (**2004**), 153.

[8] Bhattacharyya D and Brown R.H .Sensitivity of Ring-Compression Test, Metalworking Lubrication, S. Kalpakjian and S.C. Jain, Ed., The American Society of Mechanical Engineers, New York, (**1980**), 23.

[9] Schey J.A, Venner T.R and Takomana S.L. *Journal of Mechanical Working Technology*, 16, (**1982**), 22.

[10] Carter WT, Lee D. *Transactions of ASME,* (**1986**),108.

[11] Venugopal S, Srinivasan G, Kvenkadesan S and Seetharaman V. *Journal of Mechanical Working Technology,* l9, (**1989**),261.

[12] Forcellese A, Gabrielli F, Barcellona A, and Micari F. *J. Mater.Process. Technol.*, Vol. 45, (**1994**), 619.

[13] Li L.X, Peng D.S, Liu J.A, Liu Z.Q and Jiang Y, *Journal of Materials Processing Technology*, 102, (**2000**),138-142.

[14] Hayhurst D.R, Chan M.W. *International Journal of Mechanical Sciences*, 47, (**2005**), 1.

[15] Danuta Szeliga, Jerzy Gawad, Maciej Pietrzyk, *Computers Methods Appl. Mech. Engg*., 195, (**2006**), 6778.

[16] Pradeep L. Menezes , Kishore , Satish V. Kailas. Influence of surface texture on coefficient of friction and transfer layer formation during sliding of pure magnesium pin on 080 M40 (EN8) steel plate, Wear, 261, (**2006**), 578.

[17] Pradeep L. Menezesa, Kishore, Satish V. Kailas. *Journal of Materials Processing Technology*, 208, (**2008**), 372.

[18] Meyers M A., Chawla K K. Mechanical behaviour of materials, Prentice Hall, (**1997**), New Jersey.

[19] User's manual. MSC.Marc, MSC Software Corporation, Santa Ana, (**2005**), California, USA,

[20] User's manual. Surfer, Golden software, Inc. (**2002**), Colorado, USA.