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Archives of Applied Science Research, 2011, 3 (4):328-335
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ISSN 0975-508X
CODEN (USA) AASRC9

Prediction of coefficient of friction for Aluminum Billet

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ABSTRACT

In the metal forming process, a realistic frictional coefficient must be specified at the die/work piece interface. Several methods are developed to evaluate friction coefficient 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. One such map is generated for aluminum for three aspect ratios. Simulation and experimental verification of this map also attempted to show the accuracy of one map.

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 [1] and later improved by [2].

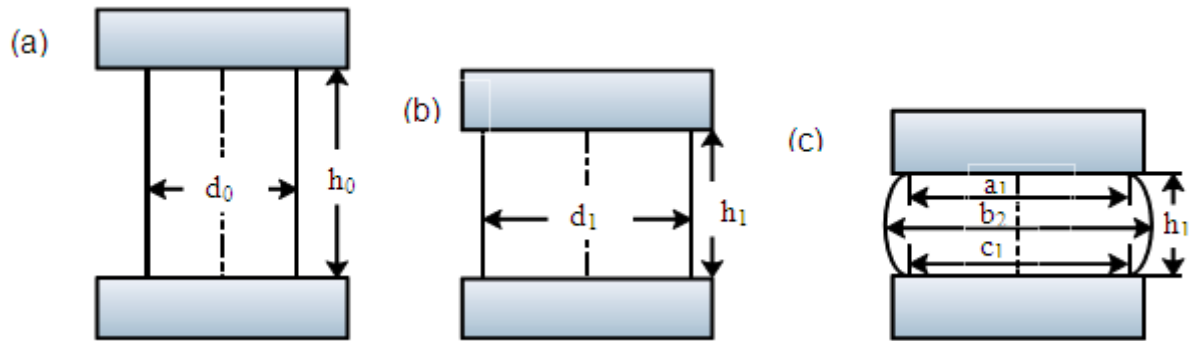
The analysis of [3] formed the bases for most of the subsequent work on ring compression test. The interfacial friction in axisymmetric upsetting of rings using a constant coefficient friction was characterized by [4]. An alternative approach of describing friction using interfacial zone of material of constant shear strength and friction factor model for upsetting of cylinders and rings was used by [5]. The ring compression test to measure coefficient of friction was used by [6]. 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 was developed by [7]. Ring compression test using physical modeling and FE simulation was studied by [8]. Aluminium and copper materials were tested to determine the values of interfacial friction by [9]. The effect of friction on pressure in upsetting considering different geometries of cylindrical billet was identified by [10]. Interfacial friction in axisymmetric upsetting using a constant coefficient of friction was characterized by [11]. The friction factor by means of Reduced Capacity Test was determined by [12]. Friction in cold metal forming was evaluated by [13]. [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. The two-parameter friction model is used by [15] for the calibration of friction models for metallic die–work piece interface. An application of the inverse analysis was presented by [16] to the identification of friction in metal forming. The effect of surface structures of hard surfaces on coefficient of friction was studied by [17]. The effect of surface roughness and surface texture on friction was studied by [18]. Experimental research and numerical simulation of ring compression was performed by [19]. The experiments have been carried out on the lubrication condition of talc powder, vaseline, vegetable oil and without lubricant. DEFOERM 2D software was used to simulate the ring compression test. The friction coefficients of different lubrication were obtained according to the friction calibration curves, which is quite useful for the numerical simulation of metal forming process. A comprehensive analysis on the influence of surface roughness and material strength in friction was provided and proposed a new operator based on a sigmoid function [20]. The presentation is supported by thoroughly researched quantitative data obtained from experimentation and finite element modelling of the ring compression test. The deformation characteristics in detail in ring compression, especially at the tool/workpiece interface was studied by [21]. Design of optimum preform for near net shape manufacturing in upsetting process design is arrived by [22] using artificial neural networks (ANN) by considering different unequal interfacial friction conditions between top and bottom die and billet interface.

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_0 and h_0 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.



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

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 [23]:

$$\sigma = K \cdot \epsilon^n \quad (1)$$

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 Figure 2.

FE Simulation

Finite element analyses of the upsetting process are carried out using MSC.Marc software [19] [24]. Taking advantage of the symmetrical conditions, axisymmetrical formulation is adopted. Four noded quadrilateral elements are used for the FE modeling. There are 800 elements and 861 nodes in the model shown in Fig.3. 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 (Fig. 2), 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.4. Diameter ratios R_1 & R_2 of the final deformed geometry of billet are noted for the map generation purpose.

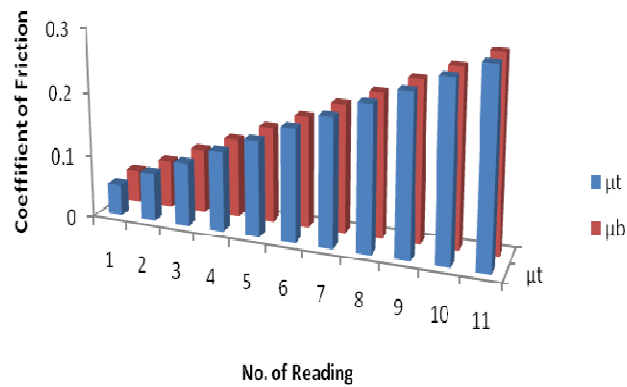


Figure 2: Friction conditions at die and billet interface

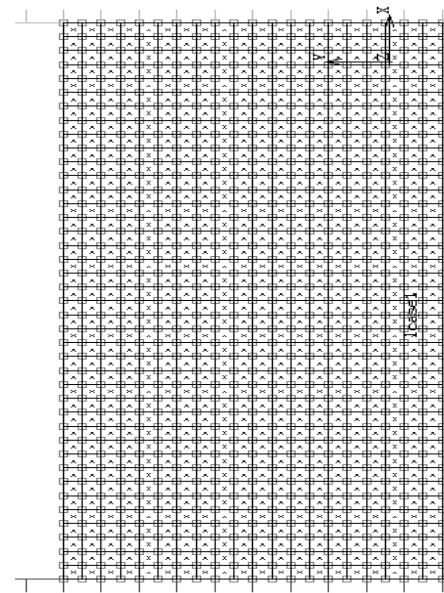


Fig 3 FE model of the undeformed billet

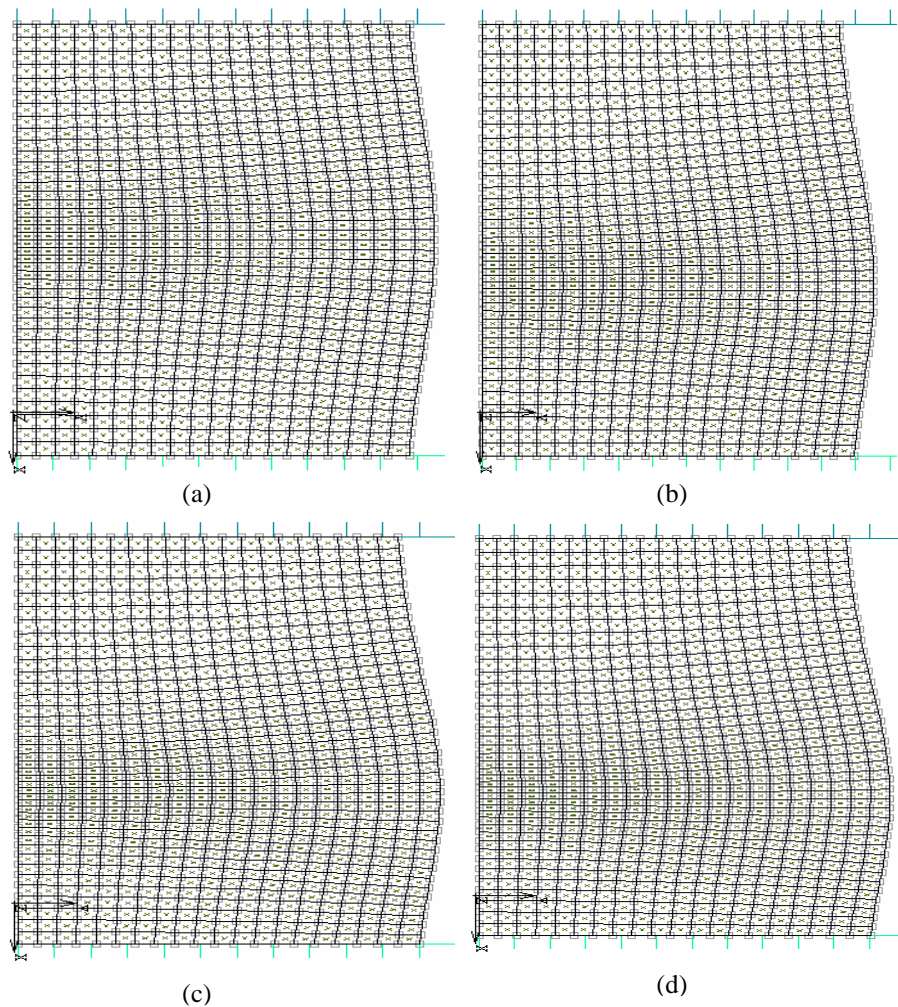


Fig 4 Deformed FE mesh for different frictional conditions (a) $f_t=0.1$, $f_b=0.1$ (b) $f_t=0.2$, $f_b=0.15$ (c) $f_t=0.3$, $f_b=0.25$ (d) $f_t=0.4$, $f_b=0.35$

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 are generated as shown in Fig. 5, in this figure solid and broken line represent f_t and f_b respectively. Software SURFER software (20) has been employed for this purpose [25]. These calibration maps can be used as a means of determining the frictional conditions using the deformed geometry data.

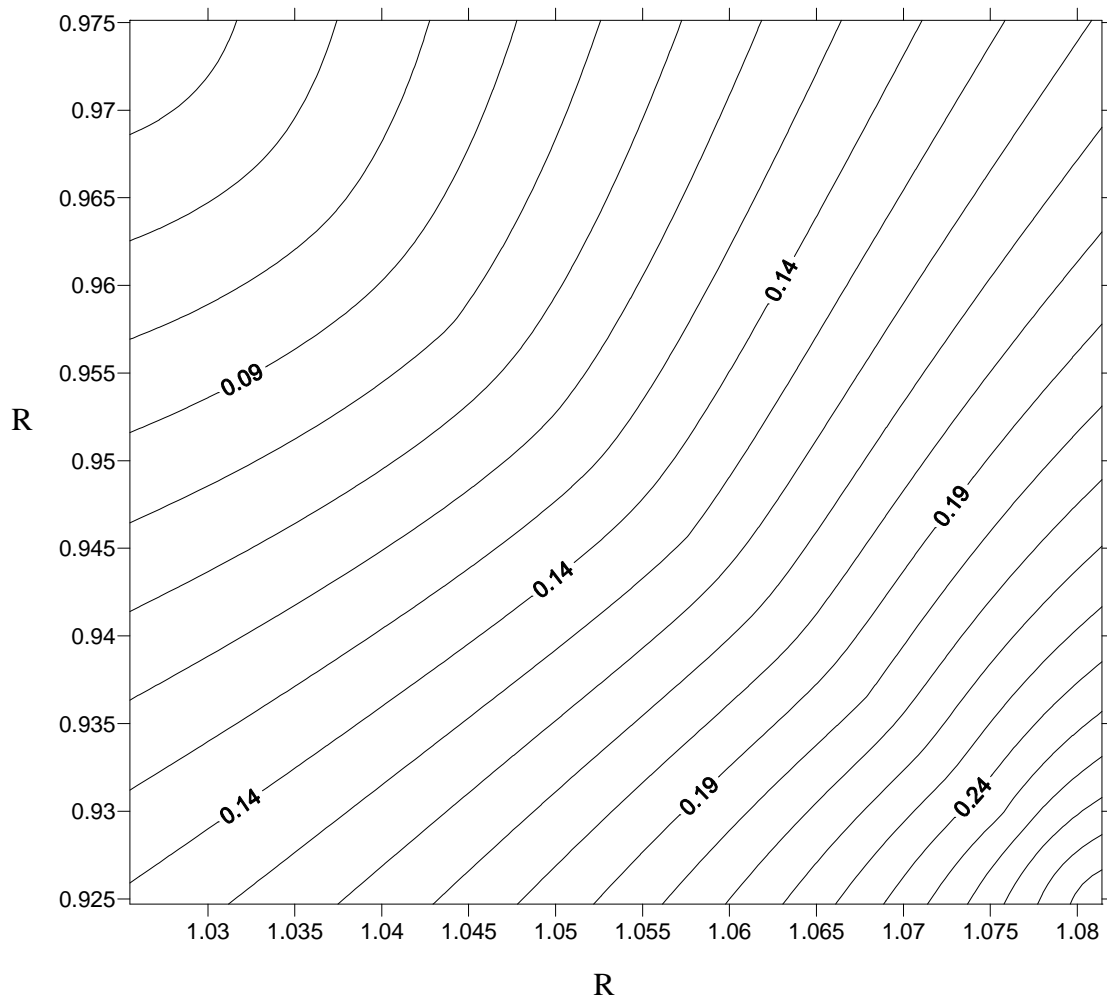


Fig 5. Friction calibration map of 30 mm aluminum

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 aluminum specimens of size 40 mm diameter and with 30 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 ring 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). This ring was subjected to compression in a standard compression Testing Machine using case hardened steel plates. A maximum load of 500 KN was applied and the ring was compressed in 2-3 stages, with a 2 mm displacement of the top plate at each stage. Lubricants were not applied to the top, bottom and lateral faces of the ring specimen after each stage of compression. The specimen, after each stage of compression was cleaned and for the next stage of compression. Figure 6 shows the specimen that was 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 aluminum ring of internal diameter 20 mm, external diameter 40 mm and height 13.33 mm for ring compression test is shown in Table 1.

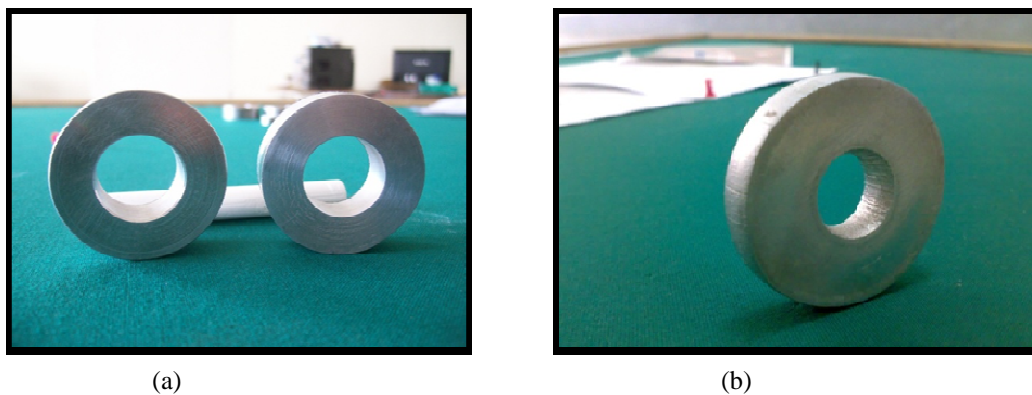


Figure 6 (a) Aluminum ring before compression (b) Aluminum ring after compression

Table 1 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

Compression of aluminum 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 plates. 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 plate at each stage. The specimen, after each stage of compression was cleaned and for the next stage of compression. Figure 7 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. Table 2 shows the dimensions before and after deformation.

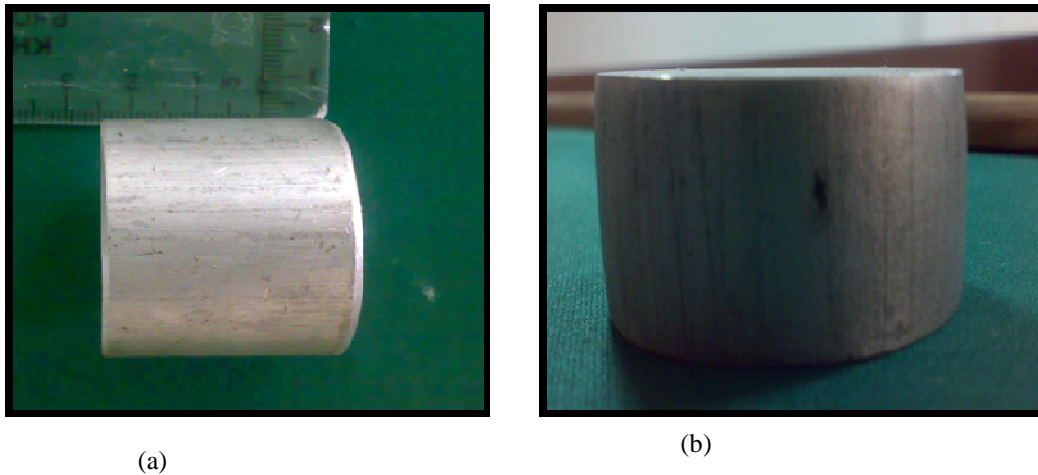


Figure 7 (a) Aluminum billet of height 30 mm diameter 40 mm before compression

(b) Aluminum billet of height 30 mm diameter 40 mm after compression

Table 2 Experimental data of Billet for dry condition

S. No.	Size	D1	D2	D3	H	$R_1=(D_1/D_3)$	$R_2=(D_2/D_1)$
1	30	48.3	45.6	45.6	21	1.059210526	0.944099379

Numerical Validation

Several examples are presented to show the efficacy of the friction calibration map on aluminum upsetting. Cylindrical billet of 30 mm diameter and 40 mm height is simulated by considering newer interface frictions as given in the Table 3. 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 is 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 3 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	1.059210526	0.944099379	0.17	0.16	0.064
	30	1.061946903	0.941666667	0.06	0.066	0.1

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.

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