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Effect of Friction on Barreling during cold Upset Forging of Aluminium 6082 Alloy Solid cylinders

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Abstract. Friction is one of the significant factors in forging operations since it affects metal flow in the die, forming load, strain distribution, tool and die life, surface quality of the product etc. In upset forging, the frictional forces at the die-workpiece interface oppose the outward flow of the material due to which the specimen develops a barrel shape. As a result, the deformation becomes non-uniform or inhomogeneous which is undesirable. Barreling can be reduced by applying effective lubricant on the surface of the platens. The objective of the present work is to study experimentally the effect of various frictional conditions (dry, grease, mineral oil) on barreling during upset forging of aluminum 6082 solid cylinders of different aspect ratio (length/diameter: 0.5, 0.75, 1). The friction coefficients are determined using the ring compression test. Curvature of barrel is determined based on the assumption that the curvature of the barrel follows the geometry of circular arc.

1. Introduction

Aluminum alloy 6082 is an excellent combination of strength, formability, corrosion resistance and recyclability. These characteristics have made 6082 alloy one of the most popular aluminum forging alloy and as a result finds application extensively in making automotive suspension components. Open die forging and upsetting are one of the commonly used processes in metal forming. It has been observed that several studies are being carried out on cold upset forging of solid cylinders by many investigators due to its significance in metal forming applications [1]. Upsetting test is one of the commonly used techniques for understanding material behavior undergoing severe plastic deformation. Such tests help in determining the material characterization in terms of flow stresses, friction-dependent factors as well as forming limit curves up to plastic instability and fracture.

Frictional conditions affect the deformation behavior and material flow of the work piece during forming operations, especially in upsetting When a solid specimen of any cross section namely, cylindrical, square or rectangular is upset forged between the punch and the bottom platen, interfacial friction between platen and the specimen resists the flow of material at the contact face and in its surrounding area. The work material towards the central part of the specimen does not suffer from any frictional resistance and hence, flows freely in the outward direction. As a consequence, the specimen under axial compression undergoes heterogeneous deformation. Such a phenomenon is called barreling. The degree of bulging can be reduced significantly by the proper use of lubricants. However, it very difficult to eliminate friction completely during upset forging [2]. Thus, there is a need to introduce an adjustment factor as a corrective measure that takes care of this heterogeneous deformation phenomenon which is found in most of cases while carrying out upset forging.

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Decrease in friction not only results in reducing the stresses developed in the forming tool but also decreases the direct contact between tool and work material, thus leading to longer tool life and better quality control [3]. Thus far, there are few methods that have been developed for quantitative assessment of friction in metal forming processes. The most accepted one for quantitative assessment of friction is to define either friction factor (m) or coefficient of friction (μ) at the die/workpiece interface [4, 5]. Kulkarni and Kalpak Jian showed that barrel shape can be well represented by circular arc for Al7075 specimens during upset forging. [6]. Kobayashi observed that barreling effect is more prominent as the friction increases. [7]. Lee and Altan [8] and Banerjee [9] estimated various parameters such as the strain rate, deformation amount, load versus deformation curve, yield stress distribution, and barreling profile on the upsetting of cylindrical and ring shaped specimen theoretically. Mahesh et al [10] found as the degree of deformation at contact surfaces increase, there is an increase of bulge diameter for base Al-10Si alloy and its composites. Similarly, few authors made an attempt to establish relationship between radius of curvature and dimensional output as well as density measurements. The calculated barrel radius when compared with the experimentally measured barrel radius, it was observed that a linear or straight line relationship exists between both the parameters [11]. One of the recentmost works focuses on the application of Taguchi approach in the upsetting of AA2014 cylindrical billets for optimization of process parameters to reduce the barreling effect [12]. Schroeder and Webster observed that the friction coefficient depends on lubrication conditions and not on the work materials [13]. However, Kukhar et al [14] stated that there exists a difference in indices of barrel shape during upset forging of samples made of different materials. Thus, influence of type of material (ferrous or non-ferrous) upon deformation cannot be neglected along with other factors such as aspect ratios and frictional conditions. Since some amount of ambiguity still remains as far as non-homogeneous deformation is concerned during upsetting process, deeper understanding of the barreling is required.

Since Al 6082 is one of the commonly used forging materials for various applications, there is a need of taking into consideration the typical attribute of the barrel shape of forgings during the preliminary upset forging tests that are done prior to the subsequent die-forging passes. Hence, this motivates us to study experimentally the effect of various frictional conditions (dry, grease, mineral oil) on barreling during upset forging of aluminum 6082 solid cylinders of different aspect ratio (length/diameter: 0.5, 0.75, 1). The basic idea is to establish a relation between barrel radius and the true compressive stress under various frictional conditions for different aspect ratios of specimens. The determination of barrel radius may prove helpful for the practical estimation of the power consumption during the forging process.

2. Experimental Details

2.1 Test material

Material used for the present work was AA6082 aluminum alloy. Its chemical composition is presented in Table 1. Cylindrical specimens of 32 mm diameter and different heights accordong to set of aspect ratios taken such as length/diameter: 0.5, 0.75 and 1 were prepared from AA 6082 rod using various machining operations on a lathe.

2.2 Hardness test

For checking the hardness of Aluminum specimens, Brinell hardness test was done. In this test, hardened steel ball of diameter 10 mm was used as indentor while the test material was subjected to 3000 kgf load. This method is chosen for measuring the hardness because Brinell hardness is suitable for measuring bulk or macro-hardness of materials, particularly with heterogeneous structures. The hardness for the selected grade of Al was found to be 60 BHN. This paragraph follows a section title so it should not be indented.

Table 1. Chemical Composition of AA6082 [15]

Element	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	other	Al
Comp	0.4-1.0	0.0-0.5	0.6-1.2	0.7-1.3	0.0-0.1	0.0-0.2	0.0-0.1	0.0-0.25	0.0-0.15	balance

2.3 Ring compression test

Ring compression tests were carried out with standard ring specimen ratio of 6:3:2. Ring compression tests were performed with ring samples under dry conditions as well as using lubricants same as those used in the disc compression tests. The interfacial friction can be determined either by friction factor m or coefficient of friction µ. In the present study, coefficient of friction values have been obtained experimentally using ring compression tests. A sequence of ring compression tests were conducted using CTM (Compression testing machine) on ring specimens for each condition of lubrication. Figure 1 shows the ring samples used in the experiments for different lubricating conditions.

(a) Dry (b) Grease (c) Mineral oil

Figure 1. Ring samples for different lubricating conditions

2.4 Compression test of solid cylinder

In these tests, specimens were axially compressed under three different conditions i.e. dry condition and two types of lubricating conditions. Two types of lubricants were used: oil and grease. Under lubricating conditions, lubricant (oil/grease) was applied on the top and bottom faces of the cylinders and dies by hand and whenever the specimen was removed for taking measurements, corresponding lubricant was reapplied. Extreme care was taken while placing the specimen such that the axis of the cylindrical specimen is concentric with the axis of the ram. In total, nine specimens (three different aspect ratios and three lubricating conditions) were taken and compression testing was done with intermediate dimensions being noted simultaneously.

Table 2 shows the details of the equipment used for various tests.

Table 2. Specification of Equipments

Equipment	**Specifications**		
	Make	***Max load***	***Type of loading***
UTM	Microcontrol sysem	100KN	Motorized gear
CTM	Unitech	1000KN	Hydraulic
Brinell hardness	Microcontrol system	3000 kgf	Hydraulic

3. Results and Discussions

3.1 Determination of friction coefficients

A ring with inner and outer radius is compressed during a ring test. Inner radius is more sensitive to friction as compared to outer radius and thus, by keeping a proper check on inner radius helps is assesing the frictional conditions. When coefficient of friction is low ornegligible, the inner diameter of the ring behaves in the same manner as that of a solid cylinder i.e. it increases. But when coefficient of friction is high and exceeds a critical value the inner diameter of the ring would decrease (see Fig.2(a)). Using this relationship, specific curves, known as friction calibration curves, were developed by Male and Cockcroft [4].These curves relate 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(b).

Initial thicknesses as well as specimen inner and outer diameters were measured. Specimens were freely placed on the lower die in a way that centre lines of both coincided. The instantaneous values of thickness as well as inner and outer diameters were measured. Several readings were taken for inner and outer diameters and an average value was recorded because of barrelling and irregularity on both inner and outer cylindrical surfaces of specimen. The coefficient of friction values for dry as well as lubricated conditions were determined which is shown in Fig. 2(c). It is observed that on application of lubricants such as grease and mineral oil, frictional coefficient values have greatly reduced from 0.56 to 0.32 and 0.26 respectively.

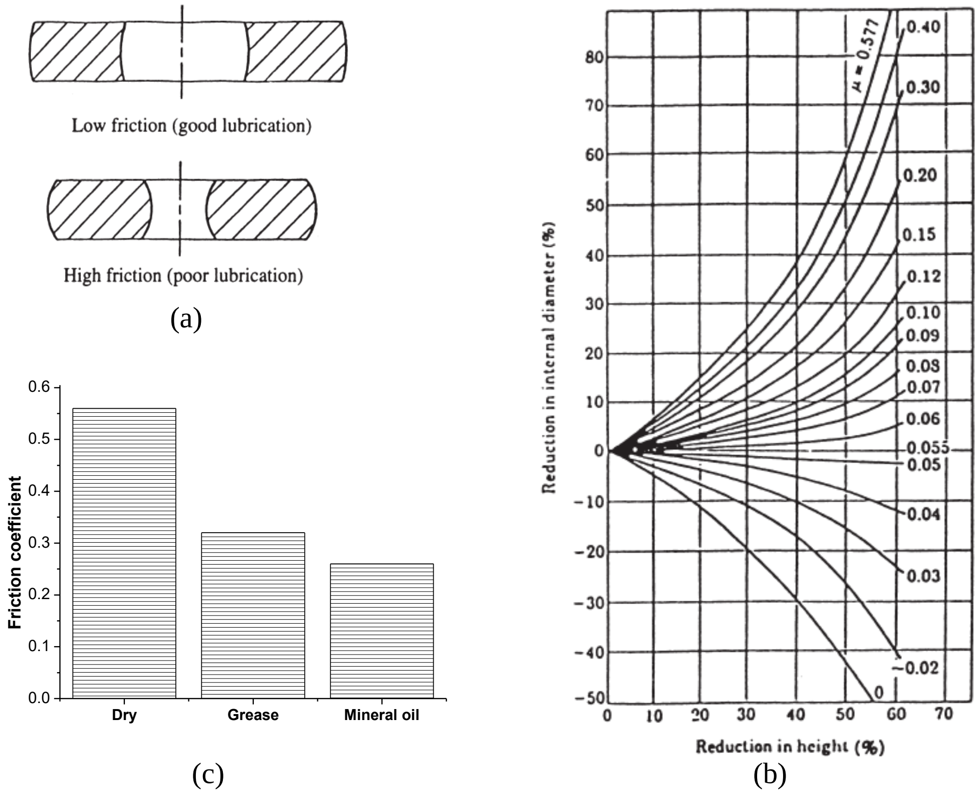


Figure 2. (a) Effect of friction on metal flow [1] (b) Friction calibration curves [2] (c) Calculated values of friction coefficient

3.2 Barreling during compression tests of solid cylinders

Firstly, the loads and the percentage reduction of heights were noted for specimens of different aspect ratios: length/diameter = 0.5, 0.75 and 1.00. Values of Maximum Diameter and intermediate heights' were measured and noted for different compressive loads ranging from 0 to 350 kN.

Compressive stresses were calculated in each case, using following expression [9]:

$$\sigma = 8F/\pi\left(3H_o D_o^2 / H - D_2^2\right) \tag{1}$$

where σ is the compressive stress, F the load applied, H_o and D_o the initial height and initial diameter, respectively of the cylinder, D_2 and H are the maximum diameter and instantaneous height of the specimen respectively. It is noted that the above expression is derived assuming volume to be constant throughout process.

Radius of curvatures for the barrel shape was determined theoretically, given as follows [10]:

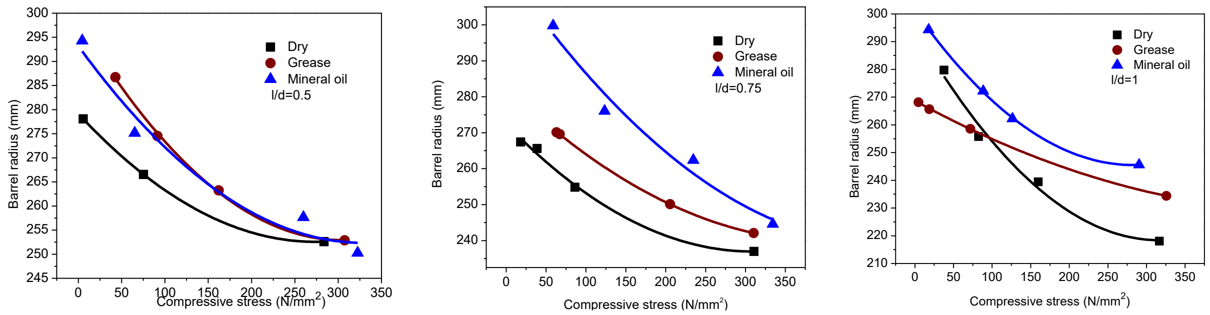
$$R = \frac{\left(H^2 + \left(D_2 - D_1\right)^2\right)}{\left(4\left(D_2 - D_1\right)\right)} \tag{2}$$

where

$$D_1 = \sqrt{\frac{3H_o D_o^2}{H} - 2D_2^2} \quad . \tag{3}$$

The details of the formulation for the above expressions can be found in Ref [10].

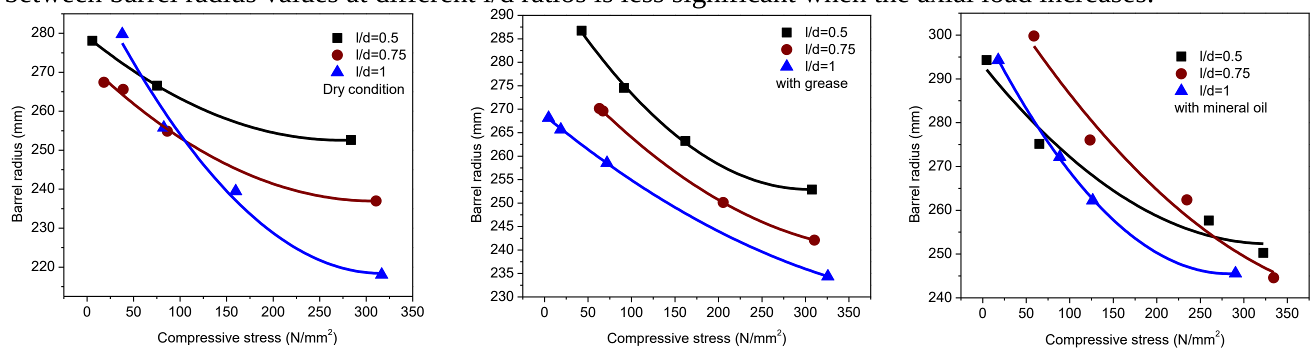
The barrel radius after each stage of loading was plotted against the corresponding compressive stresses at different lubricating conditions (μ= 0.56, 0.32, 0.26 for l/d 0.5, 0.75 and 1 (see Figure 3). Greater value of radius of curvature indicates less barreling. For ideal interfacial conditions, the radius of curvature would tend to infinity indicating perfectly homogeneous deformation with no barreling [10].



(a) (b) (c)

Figure 3. Barrel radius versus compressive stress for (a) l/d=0.5 (b) l/d=0.75 and (c) l/d=1

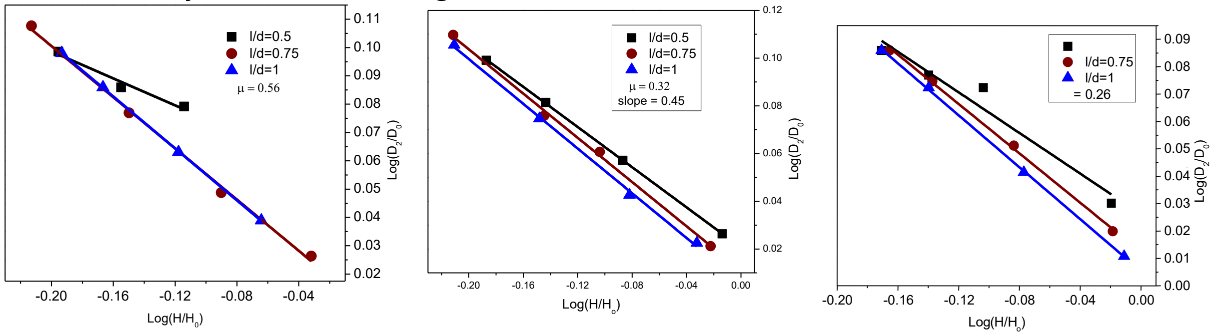
It is observed that for all the aspect ratios considered, especially for higher l/d ratios, barreling effect is distinctively prominent under dry conditions as compared to that of grease and mineral oil. This is well understood from the lower values of radius of curvature obtained in case of dry conditions for different aspect ratios. Figure 3 (a) suggests that difference between the barrel radius values under dry and lubricated conditions becomes less significant for higher values of axial load. Similar kind observations were found in Ref [9]. This is attributed to the fact that under high pressure more material to material contact between cylindrical specimens and platens occurs, thus increasing the friction and reducing the effect of lubricants used. However, as the l/d increases (see Fig. 3(b) and 2(c)), it is found that barrel radius values are different for different lubricating conditions when the axial load is high. One probable reason could be barreling becomes more sensitive with higher values of l/d and proper lubricating surface conditions even at higher loads could alter the frictional conditions at the interface and modify the barreling effect to some extent. Figure 4 shows the effect of l/d ratios on variation of radius of curvature with increase in compressive stresses under different lubricating conditions. It is observed that for all the three cases, barrel radius for l/d ratio as 1 gives the lowest values of radius of curvature while l/d 0.5 gives the highest values indicating the fact that as l/d ratio increases the chance of getting barrel shape also increases for same value of μ. Again, as the μ decreases, the difference between barrel radius values at different l/d ratios is less significant when the axial load increases.



(a) μ= 0.56 (b) μ= 0.32 (c) μ= 0.26

Figure 4. Barrel radius versus compressive stress for different lubricating conditions

Figure 5 shows the relationship between instantaneous maximum diameter and the instantaneous height for different aspect ratios under different frictional conditions.
It is understood that slope of the plots remains same for aspect ratios 0.75 and 1 under different lubricating conditions. While for aspect ratio 0.5, observations are slightly different. The slope is fairly less steep for l/d 0.5 when μ value is high and becomes steeper for lower values of μ. This implies that when μ value is high i.e. under dry condition for the specimen with l/d 0.5, change in diameter is not affected much by the reduction in height.



(a) (b) (c)

Figure 5. Relationship between instantaneous height and maximum diameter

4. Conclusions

The radius of the barrel decreases exponentially with increasing true stress. Barreling effect is distinctively prominent under dry conditions as compared to that of grease and mineral oil. Difference between the radius of curvature under dry and lubricated conditions becomes less significant for higher values of axial load for l/d 0.5. As l/d ratio increases the chance of getting barrel shape also increases for same value of μ.As the μ decreases, the difference between barrel radius values for different l/d ratios is less significant when the axial load increases.

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