Investigation of Friction Measurements at CSM for Hot Steel Forging Applications

Keith P. Savage
Undergraduate
Department of Metallurgical and Materials Engineering
Colorado School of Mines
Golden, CO 80401
United States of America
Chester J. Van Tyne* (Advisor)
FJERF Professor
Department of Metallurgical and Materials Engineering
Colorado School of Mines
Golden, CO 80401
United States of America

Abstract

Interfacial friction between forging dies and workpiece has a significant effect on forging applications, impacting die-wear, forming quality and deformation loads. The ring compression test is a simple, inexpensive and reliable means of quantifying the friction factor *(m)* for different materials, forging conditions, and lubricants. Undergraduate forging and forming classes at Colorado School of Mines have used existing equipment to do ring compression tests on softer metals like aluminum, but the purpose of this investigation is to determine if the equipment at CSM is capable of handling the test on heated steels. A series of tests were run using 8620 steel heated to 1000°C, then deformed on a 100 kip MTS load frame with H-13 flat dies. The results" were consistent with predictions and demonstrated that existing facilities at CSM are capable of performing the ring compression test on hot steel reliably. Four industrial lubricants from Acheson Industries were evaluated -Deltaglaze 153, Deltaforge 1105, Dag 137 and Deltaforge 907. All four lubricants exhibited friction factors from 1.0 at low reduction to around 0.6 at higher reduction, with the Deltaforge 907 averaging slightly lower than the others.

Keywords: Friction; Lubrication; Ring Compression Test; 8620 Steel

*Corresponding author
Email address: cvantyne@mines.edu
Phone: 1-303-273-3793
Fax: 1-303-273-3795

I. Introduction

Ideally, metal forging would involve perfectly smooth, frictionless dies. In reality, the friction between die and workpiece surfaces can lead to galling and pickup on the die surface, and inconsistency in the formed piece. Friction is predominantly the effect of the high pressures used and the unavoidable surface roughness in both the die and workpiece [I]. The effects of surface roughness can be alleviated by lubrication [2,3] and many different tests have been developed over the years to determine measurable values for this interfacial friction. These tests involve a variety of materials such as aluminum and copper [4], plasticine [5] and even porous steel [6], as well as various geometries such as disks [7,8,9,10], "spikes" [11], slabs [12] and strips [13].

The ring compression test has been used since the 1960's because it is a simple, inexpensive and reliable test of interfacial friction well suited to forging applications. The test uses rings of the material to be forged and is based on the assumption of a constant interfacial shear factor represented by m and a constant rate of strain hardening for each material, with friction factor values for various ring geometries represented by calibration curves [14,15]. At the totally frictionless extreme ($m = 0$), the ring would deform under compression radially outward similar to a solid disk, and the resulting reduction in height and increase in inner diameter would reflect this. However, as the interfacial friction increases, the inner radius eventually decreases as the inner surface barrels inward, and the friction factor approaches unity for perfectly "sticky" surfaces [16]. In this investigation a 6:3:2 ratio of outer diameter, inner diameter and height was used for the ring geometry. Rings machined to this ratio were deformed under simulated forging conditions and the change in dimensions of inner diameter and height revealed the amount of interfacial friction [17].

1.l Objective

The major goal of this project was to critically assess and evaluate the ring test as a method for determining friction factors for steel under hot forging conditions within the mechanical testing laboratories at Colorado School of Mines.

1.2 Research Program

This investigation used 8620 steel, which was machined into rings of appropriate dimensions and hot forged at 1000°C to different thicknesses. The measurement of hole size after deformation in conjunction with friction ring test calibration curves was used to determine the friction factor.

The use of this method for hot steel had several challenges. Among these are:

1. Determination of optimal ring size based on both ring capacity and temperature.
2. Minimization of die wear.
3. Isothermal testing conditions.
4. Proper method for lubrication application.

The purpose of the present investigation was to see if these challenges could be successfully overcome and a reliable laboratory method developed.

2. Experimental procedure

Due to the availability of both raw stock and well characterized properties [18], AISI 8620 low-carbon steel was selected for this investigation. The composition of the steel is given in Table 1. The bar stock on hand was 1 1/8" in diameter and, by leaving the outer diameter unfinished, the rings were machined to a 6:3:2 ratio of 9/8" outer diameter, 9/16" inner diameter and 3/8" height. Two sets of rings were cut; the first set, for the proof-of-concept tests, was bored out and cut with a band saw with minimal finishing. The end results had visible grooves in the top and bottom surfaces and the measured heights varied from 0.380" to 0.405" rather than the desired 0.375". This was adequate for the first two phases of testing. The second set of rings was bored and cut in an identical manner, then ground to a uniform height (~0.385") and an average surface roughness of 0.0646 mil for the final phase test run.

Table 1
Composition of 8620 steel in weight percent. (from ref 18)

C	Mn	Si	Cr	Ni	Mo	P	S
0.20	0.80	0.25	0.53	0.62	0.19	0.01	0.014

A 100 kip MTS load frame was used for this investigation, configured with H-13 flat dies. Initial calculations, based on the high temperature yield strength of 8620 steel and the capacity of the load frame, indicated that a 50% height reduction of the heated samples would not exceed the capabilities of the equipment even at high friction. In order to isolate the load cell from exposure to the heat of the dies, an insulating ceramic plate was inserted between the load cell and the H-13 die.

The general process was fairly straightforward. For each test run, a set of rings was heated in air in a resistive furnace to 1000°C for 45 minutes. One ring at a time was removed from the furnace and compressed, with no attempt made to remove scale from the samples before compression. Four measurements of outer diameter, inner diameter and height were taken and averaged, both before heating and after deformation. The outer diameter measurements were not required for the calibration curves, but were used to determine a rough *(i.e.* not accounting for bulge geometry) change in volume value that was used as a spot check of consistency.

The actual tests were broken into three phases. The first phase was intended to determine that the equipment was configured appropriately and would work as planned. The second phase went further and verified the actual process by adding a lubrication step. The third phase and final phase applied what was learned in the first two phases to evaluate four different industrial lubricants.

2.1 *PhaseI*

Ten rings from the first set of rough-cut samples were selected of approximately the same size (-0.400"). Five different reductions were planned and, in the interest of pure experimentation, one ring of each reduction was either air cooled or water quenched. (The results were equivalent with respect to cooling method; if there was any variation in two cooling methods, it was lost in the measurement "noise".) Dimension measurements were recorded before the rings were heated and compressed. The platens were at room temperature at the start of the test run and the first and last pairs of rings were compressed the same amount to determine if there would be any significant change as the ten samples gradually heated the platens. (Again, any variation was in the measurement noise, so no discernable effect could be inferred.)

2.2 *Phase II*

Nine more rings of roughly equal height (--0.385") from the first set of rough-cut samples were selected and measured for the next test. For this phase, the platens were warmed prior to testing to approximately 80°C with an electric hot-plate. The rings were deformed in 5% increments to about a 45% reduction in height. Graphite powder was applied to the lower platen and sprinkled on the top of each ring as it was removed from the furnace and placed on the die, though the tendency was for the powder to lump up and roll off the top of the hot rings leaving the top surface less uniformly lubricated.

2.3 *Phase m*

For the final set of tests, four industrial forging lubricants from Acheson Industries were used. The first one used was Deltaglaze 153, a high temperature glass lubricant in a water-based carrier. The lubricant was used straight from the can (after stirring), rather than slightly diluted in a 5: I ratio of product to water as recommended, and was swabbed onto the platens with paper towels. The lubricant had the consistency of a thick water-based paint and tended to dry out quickly on the warm platens, leaving a slightly uneven surface for pressing, and a visible residue on the rings after reduction. The next lubricant used was Deltaforge 1105, a soluble synthetic in a water carrier. Diluted to the recommended I: 5 ratio of product to water, the lubricant had the appearance and consistency of dishwashing soap, making it easy to swab evenly onto the platens with paper towels between each test run. The two remaining graphite-based lubricants, Deltaforge 907 and Dag 137 (the former a liquid and the latter in paste form), were diluted as recommended (I :3 and I: 10 respectively) and applied with spray bottles. Between rings, loose scale was vacuumed from the platens before the next coat of lubricant was applied. Between lubricants, the platens were cleaned with the commercial degreaser FantastikTM and reheated with the electric hot-plate for about half an hour. Six rings were tested with each lubricant (except for the Deltaforge 1105 run where only five rings were available). The rings were deformed from 15% to 50% in approximately 7% increments.

3. Results and discussion

The first phase of testing successfully showed that, with minor modifications to the process, the same methodology used in the undergraduate Forging and Forming class with hot aluminum rings could be applied to hot steel. The friction values were consistently around 1.0, as can be seen in Figure 1. This is a value indicating sticking friction, which would be expected for a hot steel forging with no lubrication. The second phase proved the process could be made to work for more complex tests. However, the data were not as consistent as the first test; this is most likely the result of incomplete application of the lubricant.

The final phase was also a qualified success. The results, as seen in Figure 2, are fairly consistent, though two trends require explanation. The first is the large variation in height measurements for the Deltaglaze samples, especially at low deformation; dried lubricant residue tended to cake onto the upper and lower surfaces and may have influenced the measurements. The second trend is the variation in friction factor between low and high deformation. This may be the result of the scale dominating the frictional effects at lower reductions while the lubricants proved more effective at higher reductions.

4. Summary

The ring compression test is a simple and effective method for evaluating interfacial friction between forging dies and workpieces. This test has been used in undergraduate laboratories at Colorado School of Mines for 13 years with hot aluminum rings. This study showed that the same equipment and general methodology can be applied to hot steel, though the presence of scale did add a level of complexity to both the procedure and the interpretation of the results.

Acknowledgments

This investigation was made possible by the sponsorship of a 2000/2001 FIERF/Finkl Challenge Grant. The technical assistance from Steve Cross and Noel Meyers, and sample preparation by Steve Donaldson is gratefully acknowledged.

References

[1] B. Avitzur, "Friction During Metal Fonning", *Metals Handbook Volume* 18 *Friction, Lubrication and Wear Technology,* ASM International, Materials Park, OH, 1992, p59- 69.

[2] R. Sharan and S.N. Prasad, "Role of Lubricants in Metal Flow and Die Wear During Forging", *Metalworking Lubrication*, S. Kalpakjian and S.C. Jain, Ed., The American Society of Mechanical Engineers, New York, 1980, p77-82.

[3] L.X. Li, D.S. Peng, J.A. Liu, Z.Q. Liu and Y. Jiang, "An Experimental Studyofthe Lubricating Behavior of A5 Glass Lubricant By Means of the Ring Compression Test", Journal ofMaterials Processing Technology, Vol102, 2000, 138-142.

[4] D. Bhattacharyya and R.H. Brown, "Sensitivity of Ring-Compression Test", *Metalworking Lubrication,* S. Kalpakjian and S.C. Jain, Ed., The American Society of Mechanical Engineers, New York, NY , 1980, p23-30.

[5] M. Tanaka, S. Ono and T. Iwadatae, "Control of Friction for Simulation Forging Using Plasticine", *Physical Modeling of Metalworking Processes* , The Metallurgical Society, Inc., Warrendale, PA, 1987, p22-34.

[6] T. Tabata and S. Masaki, "Determination of the Coefficient of Friction in Forging of Porous Metals from Ring Compression", International Journal of Mechanical Sciences, Vo120, 1978, p505-512.

[7] O.M. Ettouney and K.A. Stelson, "An Approximate Model to Calculate Foldover and Strains During Cold Upsetting of Cylinders Part I: Formulation and Evaluation of the Foldover Model", Journal of Engineering for Industry, Voll12, 1990, p260-266.

[8] O.M. Ettouney and K.A. Stelson, " An Approximate Model to Calculate Foldover and Strains During Cold Upsetting of Cylinders Part II: Use of the Foldover Model to Estimate Friction", Journal of Engineering for Industry, Voll12, 1990, p267-271.

[9] S. Venugopal, G. Srinivasan, S. Kvenkadesan and V. Seetharaman, "A Note on the Detennination of the Friction Factor By Means of the Reduction-Capacity Test", Journal of Mechanical Working Technology, Voll9, 1989, p261-266.

[10] J.A. Schey, T.R. Venner and S.L. Takomana, "The Effect of Friction on Pressure in Upsetting at Low Diameter-to-Height Ratios", Journal of Mechanical Working Technology, Vo16, 1982, p22-33.

, [11] S.lsogawa and A. Kimura, "Proposal of an Evaluating Method on Lubrication", Annals of the CIRP , Vo141, 1992, p263-266.

[12] N. Frederiksen and T. Wanheim, "Development of Friction Tests for Lubrication in Model-Material Experiments", Journal of Mechanical Working Technology, Voll2, 1985, p261-268.

[13] R. Sagar and A. Kumar, "Friction and Strain Rates in Metal Flow in Open Die Forging of Strips", *International Conference on Metal Forming Technology* 87, ASM International, India Chapter, Mutunga, Bombay, 1987, p19-22.

[14] G.E. Deiter, "Workability Tests", *Metals Handbook Volume* 14. *Forming and Forging,* ASM International, Materials Park, OH, 1988, p379-381.

[15] R.E. Dutton,V. Seetharaman, R.L. Goetz and S.L. Semiatin, "Effect of Flow Softening on Ring Test Calibration Curves", *Materials Science and Engineering,* Vol A270, 1999, p249-253.

[16] J.A. Schey, *Tribology in Metalworking,* American Society for Metals, Metals Park, OH, 1983, p450-452.

[17] G.E. Deiter, *Mechanical Metallurgy,* McGraw-Hil1, Inc., Boston, MA, 1986, p539-549. [18] M.R. Blankenau, " A Quantitative Phase Morphology Rule ofMixtures for the Calculation of Flow Stress in Two Ductile Phase Composites: Application to the Analysis of Intercritical Working in SAE 8620 Steel and to the Evaluation of Transformation Enhanced Plasticity", Ph.D. Thesis, MT-SRC-096-010, Colorado SchoolofMines, Golden, CO, 1996.

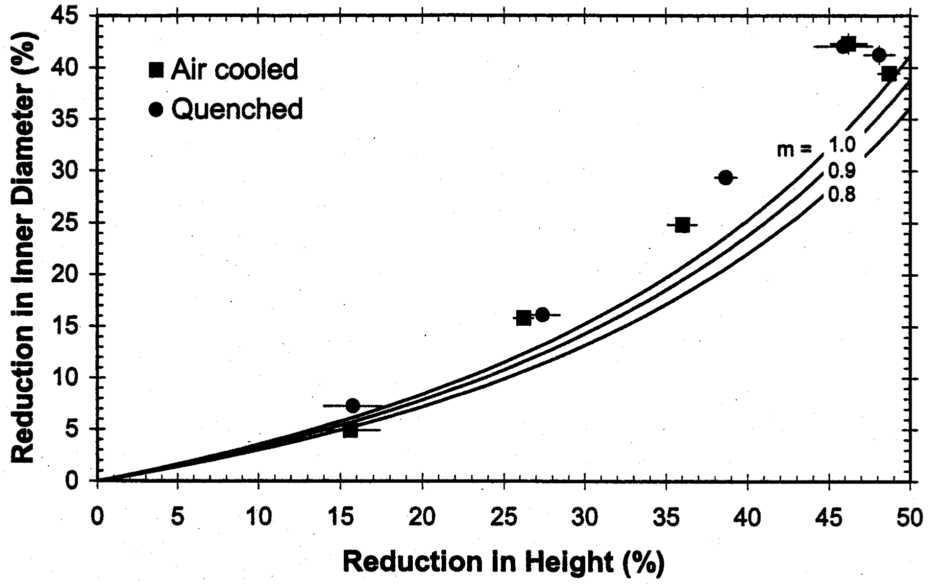

Figure 1 Plot of percent reduction in height versus percent reduction in inner diameter for the deformation of a ring. During this first phase no lubricants were used. Calibration curves show a fairly consistent friction factor value of $m = 1.0$, whether air-cooled or water quenched after forging. The error bars represent one standard deviation (plus or minus) of the final measurements as a percentage of the original height and inner diameter.

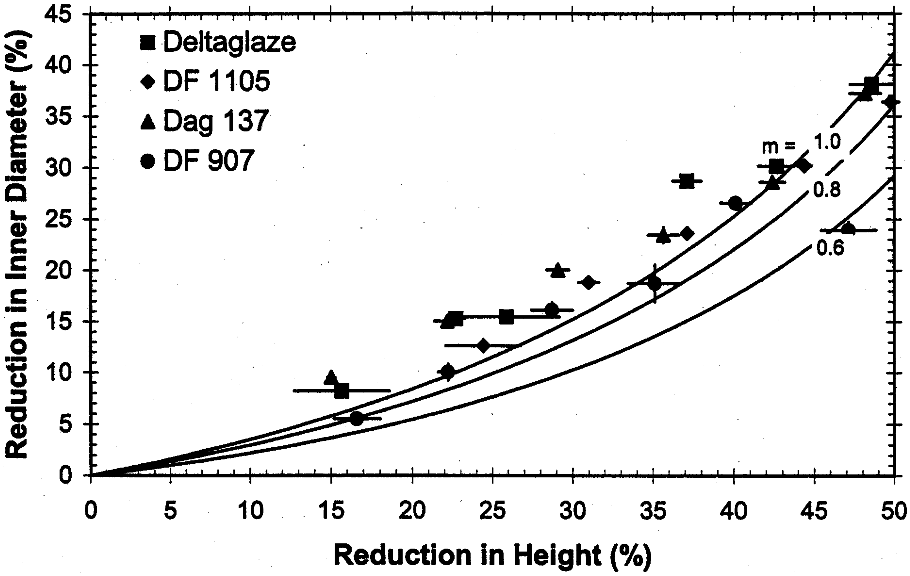

Figure 2 Plot of percent reduction in height versus percent reduction in inner diameter for the deformation of a ring. During this final phase four different industrial lubricants were used. The curves show less consistency than earlier runs, with the friction factor declining as reduction increases. The error bars represent one standard deviation (plus or minus) of the final measurements as a percentage of the original height and inner diameter.