28.0 LABORATORY TESTING TO IDENTIFY PERMANENT PVD COATINGS TO MINIMIZE LUBRICANT USE DURING FORGING

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28.1 Project Overview and Industrial Relevance

This project is establishing a process to identify how a different coating on open faced dies affects the friction associated with forging operations for given materials. These coatings are applied to open dies using physical vapor deposition (PVD), and other techniques. In order to test different coatings, a modified open die system has been designed where multiple replaceable faces/surfaces for the dies with different and unique PVD coatings on each face can be tested. This report summarizes background and recent developments.

28.2 Background

Forging dies have been manufactured and used at CSM for many years to, among other things, perform ring tests [28.1-28.3] to determine friction during forging operations. These dies are used on a 100 kip MTS hydraulic mechanical testing frame, equipped with displacement and load sensors. The current dies, pictured in Fig. 28.1a assembled on the hydraulic press, and in Figs. 28.1b and 1c individually, are both 6 inches in diameter and 2 inches in height. Fig. 28.1a shows a lubricated aluminum ring ready to be tested. Fig. 28.1c shows two protrusions on either side of the top die with a wire wrapped around both of them, which is how the top die is attached to the hydraulic press. Once the hydraulic press is lowered far enough, an upward normal force from the workpiece between the top and bottom die secures the top die in place preventing its movement. The bottom die, Fig. 28.1b, is situated below the top die and has three threaded holes evenly spaced to hold it in place on the ram of the hydraulic press. The design aspects that transferred from the current dies to the new dies are the overall outer dimensions.

Fig. 28.2 shows example aluminum rings after testing to various levels of deformation (increasing from left to right), and with different lubricants (top to bottom), where friction conditions can be quantified simply by measuring the inside diameter (ID) and outside diameter (OD) of the rings after testing. Higher levels of friction result in a reduction of the ID, whereas low friction conditions result in increases in both the ID and OD.

The design goals for the new dies are to (1) allow for interchangeable inserts with different coatings to be easily switched in and out of the die bases, (2) allow the tests to be executed with these new dies and be operable by a single individual, (3) enable the tests to be run at elevated temperatures up to 500˚C, (4) produce dies, and particularly inserts, that minimize the amount of machining required for production, and (5) ensure that valid ring-test friction evaluations can be made. The new dies have been manufactured to meet these goals, incorporating replaceable inserts to enable ring-test friction evaluations using a wide variety of die coatings, as shown in Fig. 28.3. The inserts are made from H13 or W303 tool steel heat treated to 50 HRC, and the support bases are manufactured from 4340 steel. These dies are being used to establish a baseline ring-friction test procedure by running samples at room and elevated temperature, including evaluations of multiple friction tests for a given condition to evaluate conditioning of the surfaces.

28.3 Sample Preparation and Test Procedure

Consistent sample preparation and testing procedures are being established so that the test can quantitatively measure a change in friction coefficient as a function of test conditions, including normalizing the sample preparation for the aluminum rings and uncoated die surfaces.

Aluminum ring preparation consists of EDM-sectioning 0.33 inch (8.4 mm) thick sections of 1 inch (25.4 mm) OD, 0.5 inch (12.7 mm) ID 6061 aluminum extruded tubing. The faces of these rings are then ground at 600 grit to achieve a uniform surface and eliminate marks from machining.

The die surfaces are prepared by successively grinding from 240 to 1200 grit silicon carbide papers, and then polished through 6, 3, and 1 micron diamond suspension polishing media to achieve a mirror finish. To condition the dies, two unlubricated, room-temperature ring friction tests are performed to the maximum achievable reduction (approximately 0.15 inch, 3.8 mm, final height), based on a conditioning study that showed the friction coefficient remained stable after the first ring test performed.

For room temperature tests, the following procedure is used:

- If needed, apply lubrication before loading the dies into the hydraulic press. Ensure that the lubrication is evenly distributed across the testing surface.
- Center the Al ring on the bottom die using the centering tool.
- Run test in load control at maximum allowed load, 100 kips.

For elevated temperature tests, the following procedure is used:

- The dies need to be heated to approximately 100˚ C above target testing temperature.
- Remove dies and insert into the hydraulic press (if testing with lubrication, apply after the dies are preheated for testing).
- Using a surface probe thermocouple measure the temperature as it decreases and gets near target testing temperature
- Deform to ring to height of 0.15 inches once within 10˚C of testing temperature (note loads are lower so maximum displacement can be achieved below maximum load capacity of hydraulic frame).

To date, a variety of ring-tests have been performed at room and elevated temperature, with both unlubricated and lubricated conditions. Two lubricants were used, including spray graphite and MoS_2 grease. Results from these initial tests indicate that the testing protocols are able to distinguish between friction conditions for the tests run to date, as shown in Fig. 28.5. Continuing studies on elevated temperature tests to further validate testing protocols are underway.

28.4 PVD Coatings

Four sets of die inserts have been sent out to suppliers to coat with the following four PVD coatings:

- Super MoS_2, supplied by Tribologix
- iKote, supplied by Tribologix
- CrN-Diamond Like Carbon, supplied by Phygen
- CrN-SiC, supplied by Phygen

Upon receipt, friction ring tests will be performed on the coated die sets at both room and elevated temperatures, and utilizing unlubricated or lubricated conditions, to determine the effect of coatings on friction coefficient.

28.5 Conclusions

The replaceable-insert die set for testing the relative friction coefficients of various die surface conditions has been designed and manufactured. Initial testing has been performed to show that the friction coefficients can be quantified as a function of lubrication conditions at room temperature. Elevated temperature testing on uncoated dies is underway. Four PVD coatings have been selected for testing, and die sets have been sent to suppliers for coating. Upon receipt of the coated inserts, further friction testing will be performed to quantify the relative friction coefficient for each coating as a function of lubrication condition and temperature.

28.5 References

[28.1] Male A.T. and Cockcroft M.G. "A method for the determination of the coefficient of friction of metals under condition of bulk plastic deformation.", J. Inst. Metals 1964–1965, 93, 38–46.

[28.2] Avitzur B. *Metal forming: processes and analysis.* New York: McGraw Hill, 1968.

[28.3] Sofuoglu H., Rasty J. "On the measurement of friction coefficient utilizing the ring compression test", Tribology Intl., 1999, 32, 327-335.

(a)

(b)

(c)

Figure 28.1. (a) Forging dies assembled on the 100 kip hydraulic load frame at Colorado School of Mines, showing a lubricated aluminum ring ready for testing. Ring tests are performed on the flat sides of the dies. The bottom die rests on a compression platen on the hydraulic ram, and the top die hangs from a compression platen with a spherical seat that is attached to a load cell and the press crosshead. (b) The bottom die is reversible, with a "CSM" imprint on one side and a flat face on the opposite side. The guides keep the die from sliding off the bottom ram of the hydraulic press. (c) The top die is also reversible, with an impression on one side and a flat face on the opposite side. This die hangs from the upper tooling on the hydraulic press via the pictured wires. Dies are 6 inches in diameter.

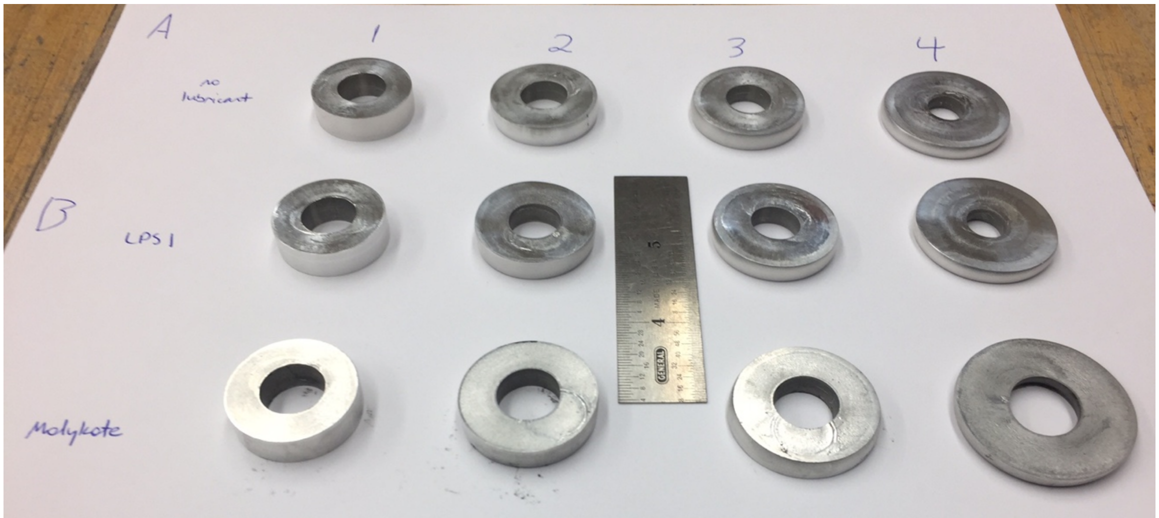

Figure 28.2. Example aluminum rings that have been tested to various levels of deformation (increasing from left to right) and using various lubricants (top to bottom) show the relative friction coefficient for the various lubricants on flat steel forging dies.

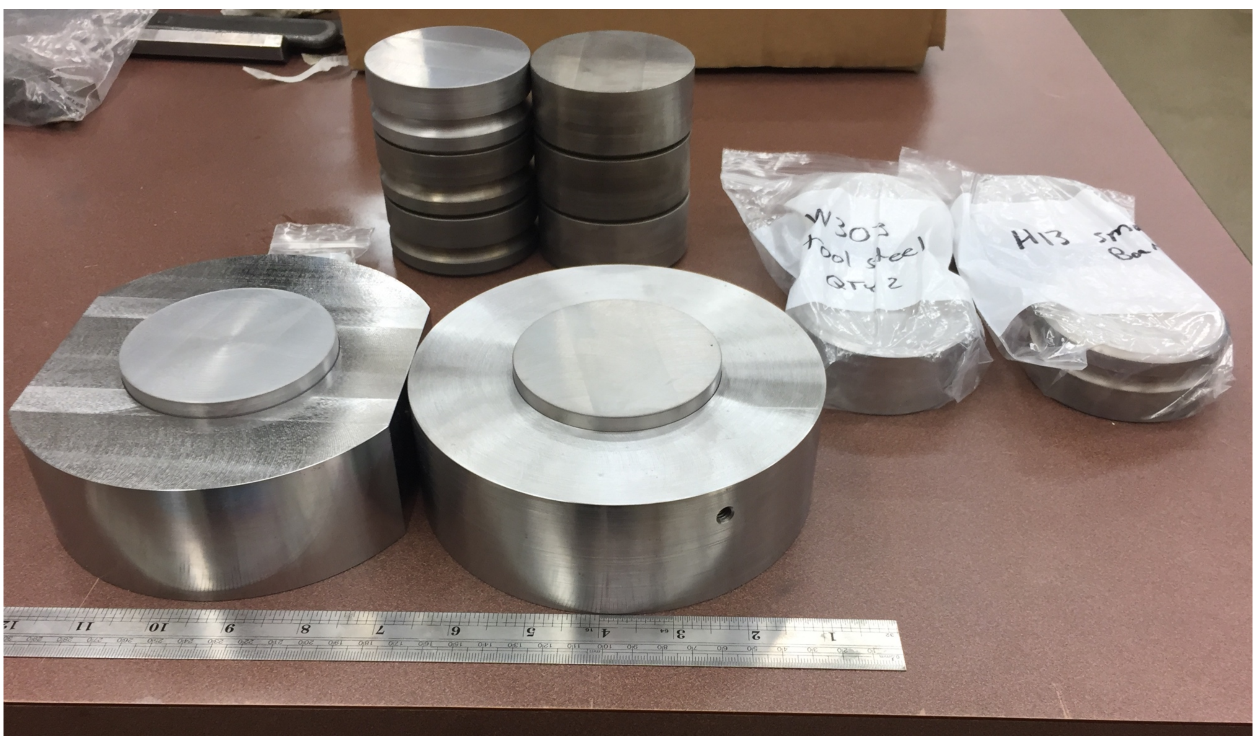

Figure 28.3. As-manufactured dies with removable inserts. One set of inserts are installed in the die based, and the five other insert sets are shown. Four sets are manufactured with H13 from Hitachi, and one set each from H13 and W303 supplied by Bohler-Uddeholm.

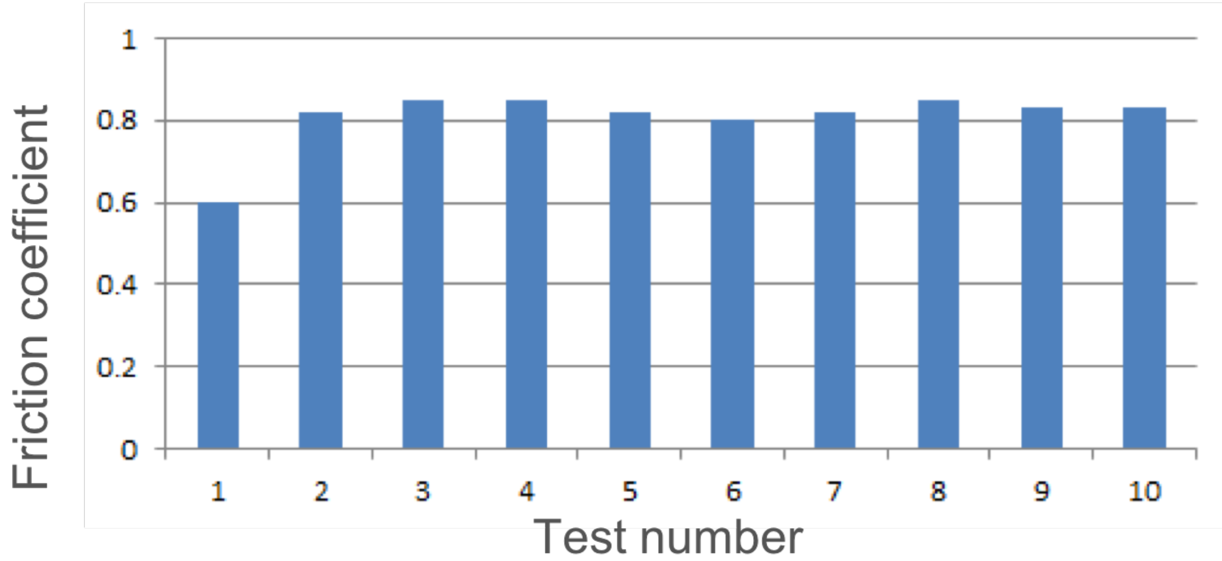

Figure 28.4. Plot of friction coefficient as measured in sequential unlubricated tests on dies prepared to a 1 micron polished finish, showing that the measured friction coefficient is consistent after the first ring test is performed.

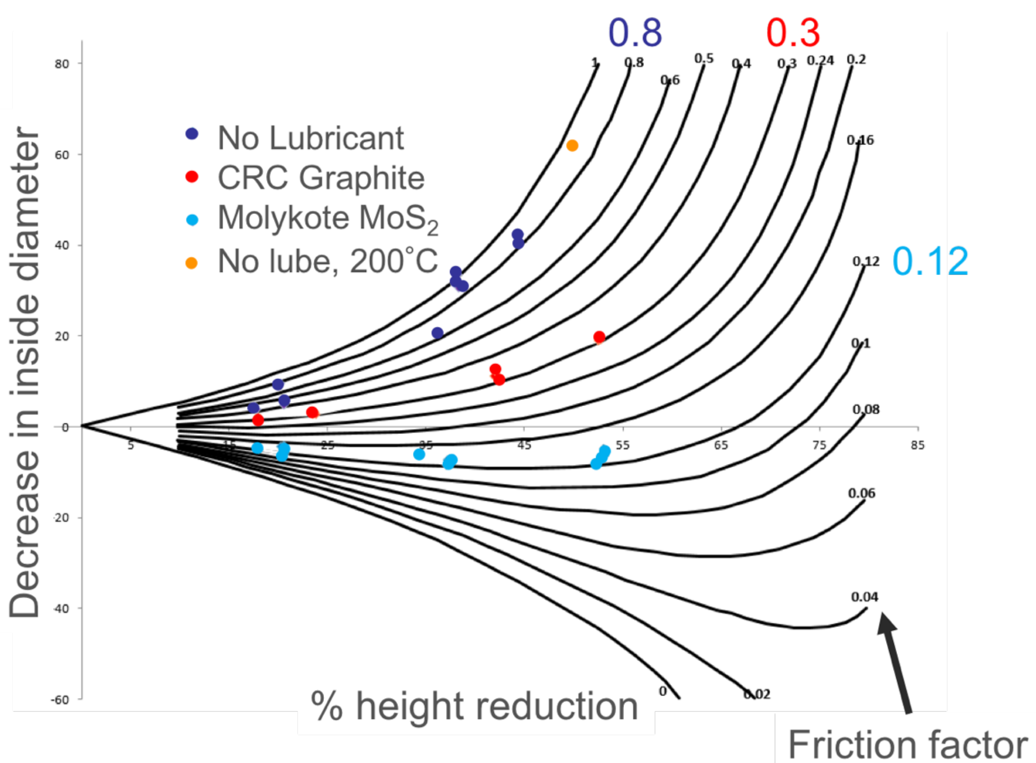

Figure 28.5. Plotted friction ring test results at room temperature (and one at 200°C) for various lubrication conditions, showing a measurable difference in friction coefficient as a function of test conditions.