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

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This project was initiated in Fall 2017 and is supported by a stage-gated grant from the Forging Industry Educational and Research Foundation (FIERF). The research performed during this project will serve as the basis for an undergraduate research program for Trevor Kehe.

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 Mines for many years to, among other things, perform ring tests [28.1-28.3] to determine friction during forging operations. These one-piece dies are used on a 100 kip MTS servohydraulic mechanical testing frame, equipped with displacement and load sensors. For this project, a new set of dies was designed and fabricated to facilitate testing of various coatings and to allow testing with die temperatures up to 500°C. 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 **Figure 28.1a and 28.1b**. 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 have been 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, examples of which are shown in **Figure 28.1c**.

28.3 Sample Preparation and Test Procedure

Consistent sample preparation and testing procedures have been 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, and details are available in a previous report [28.4].

To date, a variety of ring-tests have been performed at room and elevated temperature, with both unlubricated and lubricated conditions, and with and without various coatings. 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, and consistent friction values are obtained for multiple tests run under the same conditions, as shown in **Figure 28.2**.

28.4 PVD Coatings

Four sets of die inserts have been coated with the following four PVD coatings:

- Super MoS_2, supplied by Tribologix
- iKote, supplied by Tribologix
- CrN-Diamond-like Carbon (DLC), supplied by Phygen
- CrN-SiC, supplied by Phygen

Multiple ring tests have been performed at room temperature without lubricant to measure the friction coefficient for each of the coatings, with results presented in **Figure 28.3**. Two of the coatings, iKote and Super MoS_2, showed significantly reduced friction coefficients versus uncoated dies (friction coefficient for uncoated dies is between 0.8 and 1.0). The iKote coating, in particular, showed a friction coefficient between 0.3 and 0.4, which is a substantial reduction relative to uncoated dies. Additional repetitive tests were also performed using iKote to measure the sensitivity of the coating to multiple tests, and results are shown in **Figure 28.4**. A total of 11 repeated tests were performed under the same conditions, and the friction coefficient remained constant between 0.3 and 0.4 for each of the tests.

28.5 Conclusions

The replaceable-insert die set for testing the relative friction coefficients of various die surface conditions has been designed and manufactured. Testing has been performed to show that the friction coefficients can be quantified as a function of lubrication conditions and temperature. Four PVD coatings have been selected for testing, and room-temperature unlubricated results suggest that two of the coatings, iKote and Super MoS2, show significant reduction in friction coefficient relative to uncoated dies. Future testing of these coatings is planned to evaluate elevated temperature performance.

28.6 References

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

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

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

[28.4] T. Kehe, S. Midson, A. Korenyi-Both, K.D. Clarke, "Laboratory Testing To Identify Permanent Pvd Coatings To Minimize Lubricant Use During Forging", Fall 2019 CANFSA report.

28.6 Figures and Tables

(a) (b) (c)

Figure 28.1: (a) Manufactured die sets with removable insert pairs. A different coating can be applied to each pair of inserts to test various surface treatments, and the inserts can be separately pre-heated in an air-furnace for elevated temperature ring-tests. (b) The die set inserted on the 100 kip MTS servohydraulic test frame at Mines. (c) Example rings tested to different reductions (increasing reductions for each column from left to right) and using different friction conditions (top row is unlubricated, middle row uses graphite spray, and bottom row uses MoS_2 grease), showing the difference in ring geometry as a function of reduction and lubrication conditions.

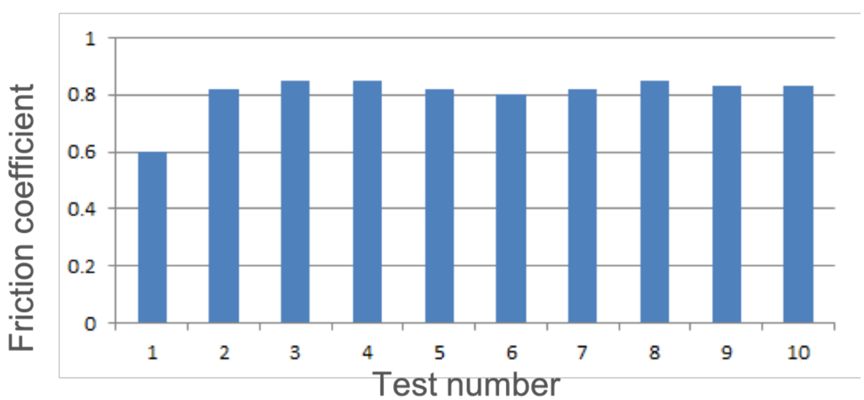

Figure 28.2: Plot of friction coefficient as measured in sequential unlubricated tests on dies prepared to a 1 µm polished finish, showing that the measured friction coefficient is consistent after the first ring test is performed.

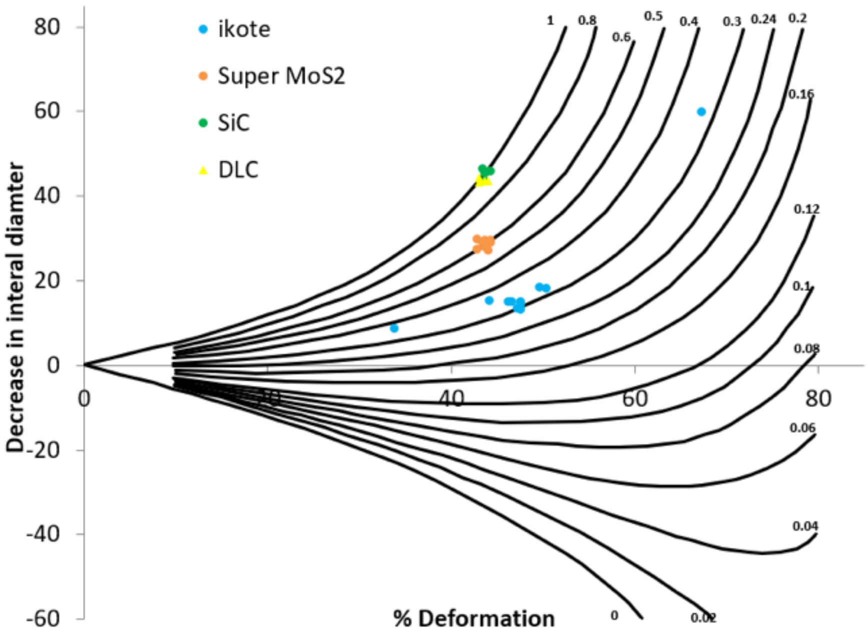

Figure 28.3: Plotted friction ring test results at room temperature without lubricant for various coatings, including iKote, Super MoS_2, CrN-SiC, and CrN-Diamond-like Carbon (DLC), showing a measurable difference in friction coefficient as a function of coating.

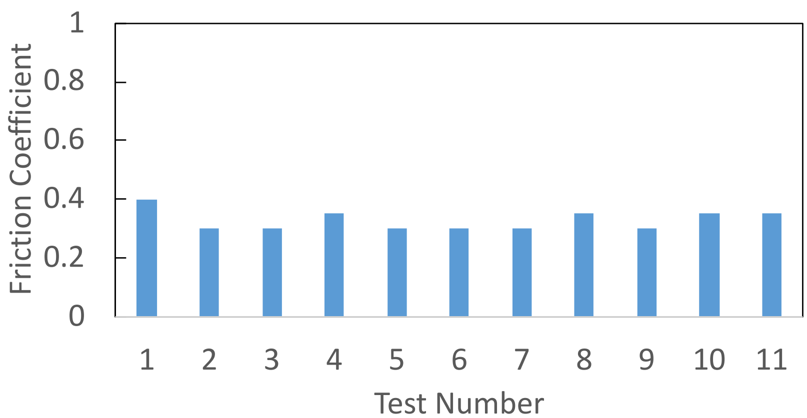

Figure 28.4: Friction coefficient for unlubricated, room-temperature ring tests for dies with iKote coating, showing that the friction coefficient remains below 0.4 for multiple tests.