Project 28: Laboratory Testing to Identify Permanent PVD Coatings to Minimize Lubricant Use During Forging

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Student: Trevor Kehe (CSM)
Faculty: Kester Clarke & Steve Midson (CSM)
Industrial Mentor: Rob Mayer (Queen City Forging)

Project 28: Laboratory Testing to Identify Permanent PVD Coatings to Minimize Lubricant Use During Forging

- Student: Trevor Kehe (Mines)
- Advisors: Kester Clarke, Steve Midson (Mines)

Project Duration
September 2017 to August 2018

Problem: Lubricants are applied to forging dies to minimize friction and optimize formability, but lubricants can decrease quality of forgings.

Objective: Reduce the use of lubricants by applying high-lubricity permanent thin-film PVD coatings to the forging tool.

Benefit: Reduce use of costly lubricants, improved cycle rate, improved quality of forgings and cleaner forging plants.

Recent Progress

- One-year project has been funded by FIERF
- Literature review of coatings used in forging and metals fabrication has been completed
- Coatings for initial trials have been identified
- Forging tool for laboratory forging test has been designed and fabrication should be complete by early May

Metrics

Description	% Complete	Status
1. Literature review	100%	●
2. Design and fabricate tooling for laboratory forging test	80%	●
3. Produce coated die samples and set up laboratory testing procedure	5%	●
4. Perform plant trial of best PVD coating identified during laboratory testing	0%	●
5. Reporting	0%	●

Project Goals

Utilize permanent PVD thin-film coatings

- Applied to forging dies
- To minimize use of die lubricants

Goals

- Reduce use of costly lubricants
- Improve die life
- Improve cycle rate
- Improve quality of forgings
- Reduce lubricant over-spray in facility

Approach Utilized for This Project

- Leverage the recent CSM "Lube Free" coating project
  - Apply similar coating technologies to forging dies
- Develop a flexible testing methodology
  - Quickly evaluate relative friction coefficients of PVD surface coatings during aluminum forging
- Working toward developments that will support higher temperature and stress forging operations for other materials
  - Titanium alloys and steels
- One year project
  - Funded by Forging Industry Educational and Research Foundation (FIERF)

Project Tasks

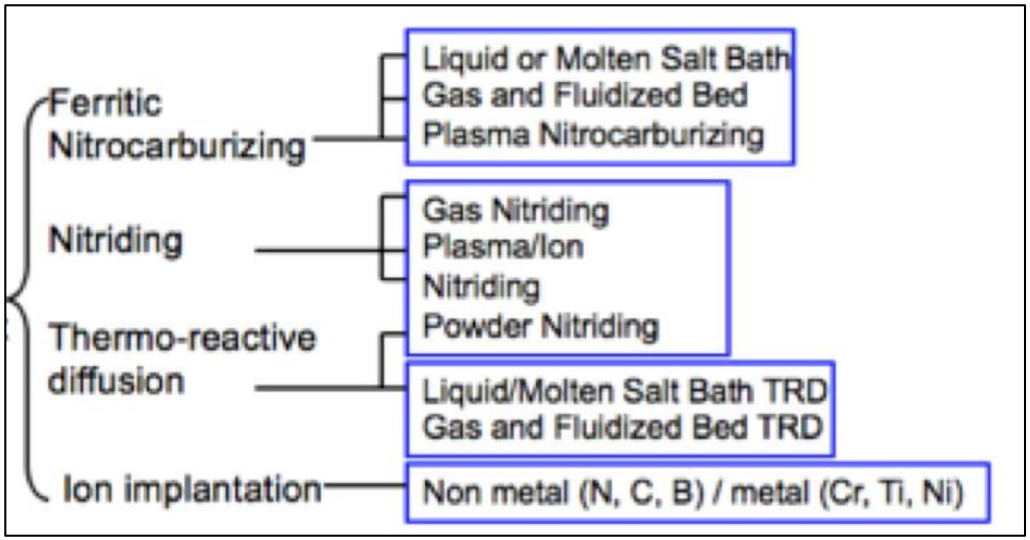
1. Perform literature review of coatings used in forging and metals fabrication
2. Design and fabricate tooling for laboratory forging test
3. Procure coated die test samples and set up laboratory testing procedure
4. Perform plant trial of best PVD coating identified during laboratory testing
5. Reporting

Task 1:
Review of Literature

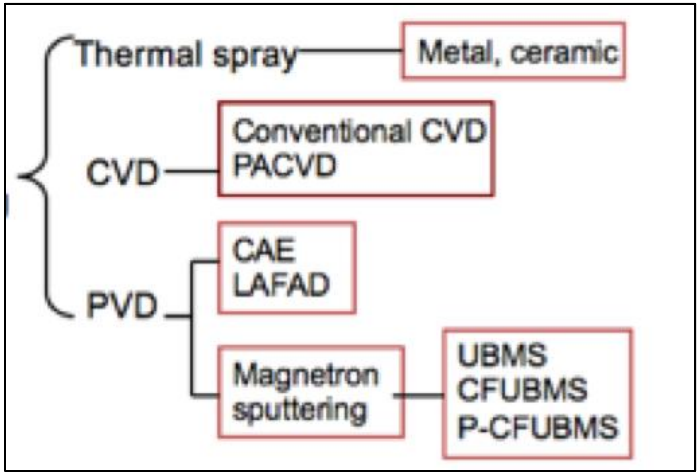
Surface Engineering Technologies

- Surface engineering can be divided into three classes

Traditional Surface Treatments



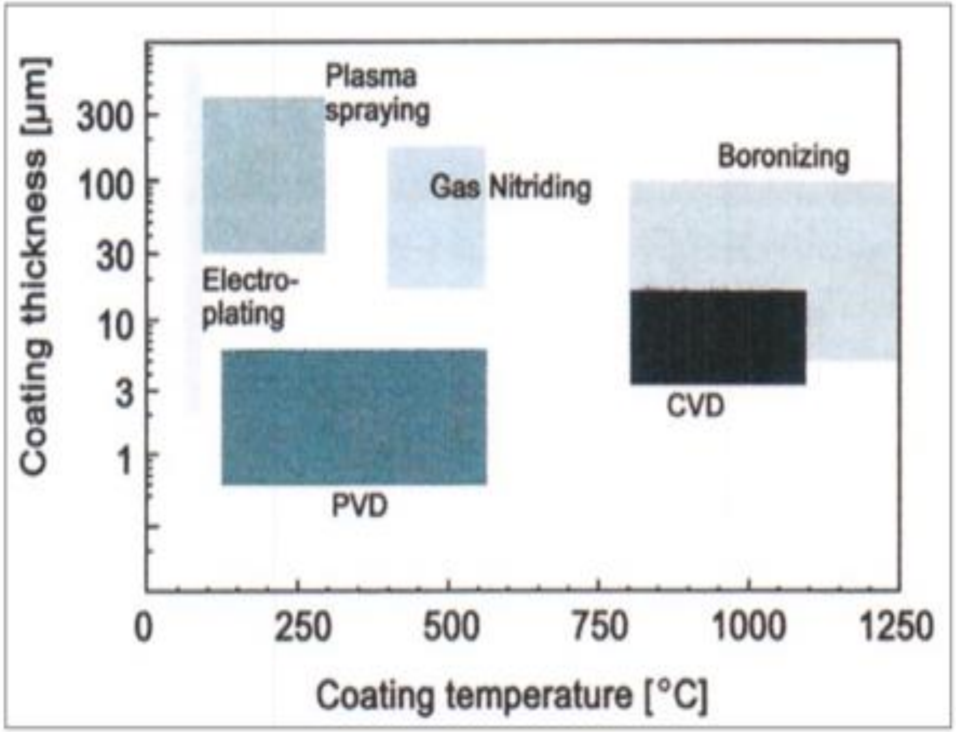
Hard Thin-Film Coatings



Weld Overlay

- Manual metal arc
- Submerged arc welding
- MIG
- TIG

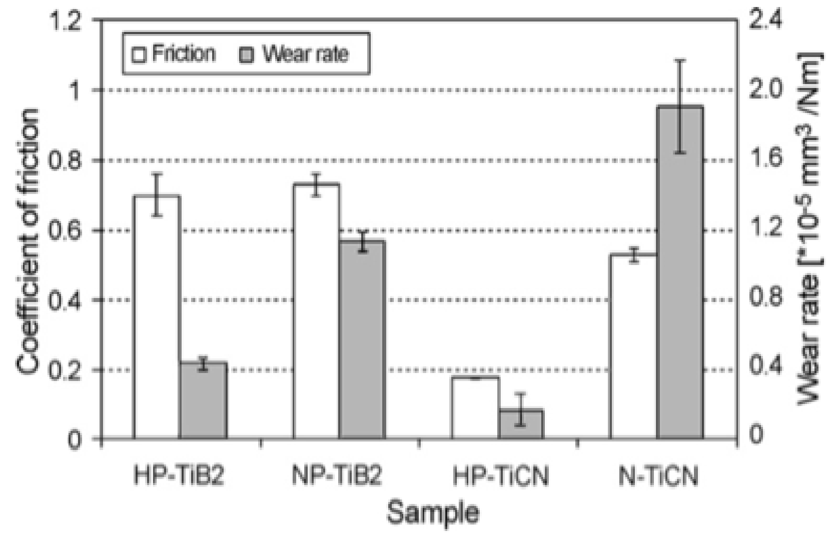
Hard Thin-Film Coatings for Forging Dies



- Coating thickness is typically <10 μm
  - Thicker coatings will spall
- Substrate temperature needs to be less than 550ºC (1,000ºF) during application
  - To avoid over-tempering of hardened tool-steel substrate
- PVD coating meets these criteria

Coatings Currently Used on Forging Dies

- PVD coatings are not commonly used on forging dies
  - More common with die casting dies
- Most of the studies have focused on wear resistance and extending die life
  - Not on improving lubricity
- Coatings examined include CrN, TiN, TiC, TiCN, TiAlCN, TiC, AlCrN, TiAlN
- Data from Leskovsek et al. showed that TiCN did reduce coefficient of friction



Source: Leskovsek et al., Wear, 2009

Current Lubricants and Potential Coatings

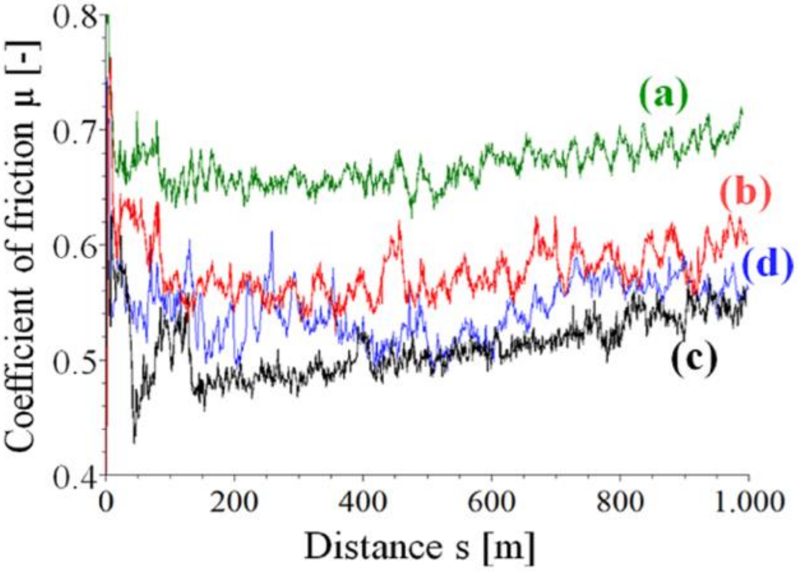
Mechanism	Material Examples	Temp. Range
Traditional liquid lubricants	Oils and greases	<~250°C
Atomic structures that can easily shear	MoS_2, graphite	<300°C
PVD hard coatings (can contain softer lubricating phases)	Diamond like carbon, TiCN, CrN/SiC, i-Kote	<500-800°C depending upon coating
Soft metals within hard coatings that diffuse to contact surfaces	Ag, Au, Cu encapsulated in TiN, CrN, VN, YSZ, CrAlN	300 – 500°C
Lubricious oxides	V_2O_5, MoO_3	500 – 1000°C

Source: Adapted from Voevodin et al., Surf. & Coat. Tech., 2014

MoS_2-Containing Coatings

- MoS_2 is an excellent lubricant
  - Due to its layered structure
- MoS_2 can be directly deposited
  - Deposited structures are very soft
  - Easily detach from substrate
- Mos_2 has been deposited as part of a harder coating
  - Titanium
  - AlCrN
    - Coefficient of friction values were reduced

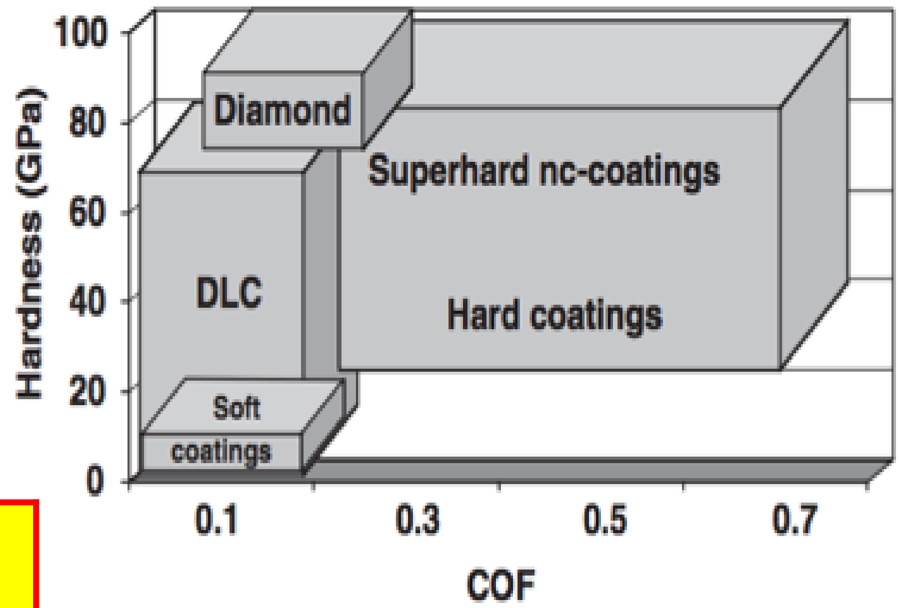
(a) Uncoated substrate
(b), (c) & (d) utilizing $(Cr_{1-X}Al_X)N/Mo_YS_Z$-type coatings



Source: Bobzin et al., Ad. Eng. Mat., 2016

Hard Coatings

- Several hard coatings have the potential for improving lubricity
  - Diamond like carbon (DLC)
  - CrN/SiC
  - TiCN



Coating	Coefficient of Friction
CrN	0.28
CrN/DLC	0.07
CrN/SiC	0.07

Sources: Mulligan et al., Mat. & Man. Proc., 2014
Donnet and Erdemir, 2008

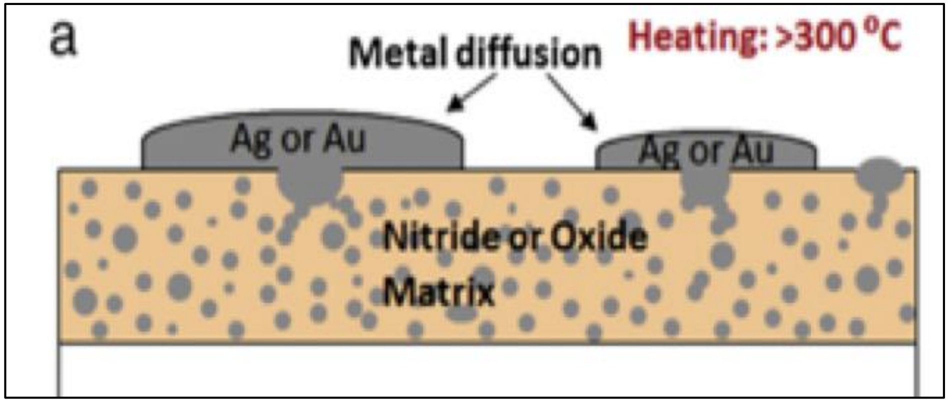
Noble Metal Solid Lubricants

Noble metals are dispersed in hard coatings

- Ag in CrN
- Ag in CrAlN
- Ag in TiC

Noble metal diffuses to surface

- Provide lubricity at temperature greater than 300°C

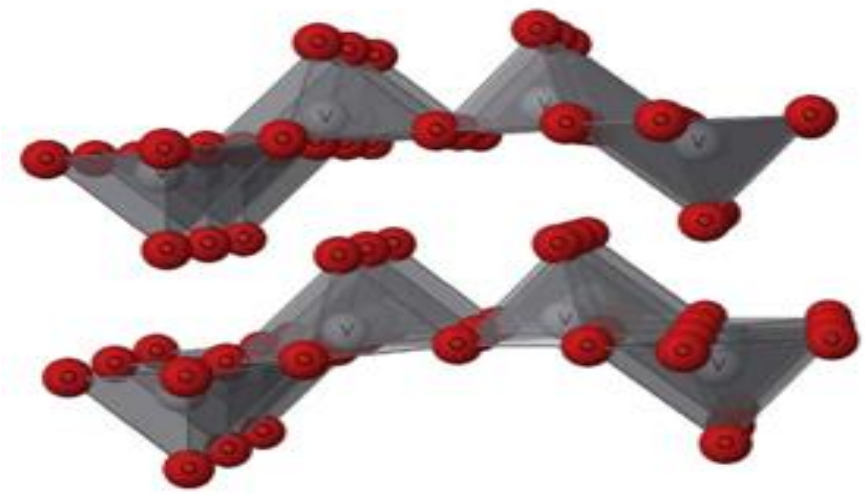


Source: Voevodin et al., Surf. & Coat. Tech., 2014

Highly Lubricious Oxide Coatings

- For applications at high temperatures
  - Unreasonable to expect materials to resist oxidation for long periods
- Utilize oxide materials
  - Having low interfacial shear strengths
  - V_2O_5
  - MoO_3

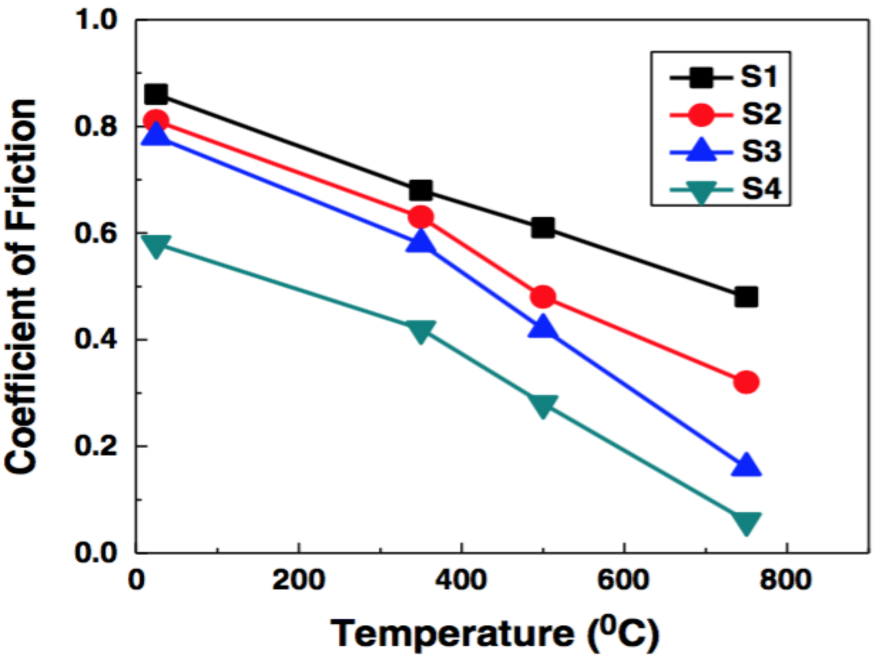
- Layered structure of V_2O_5
  - V atoms are represented as grey balls
  - O atoms as red balls



Source: Mulligan et al., Surf. & Coat. Tech., 2010

Highly Lubricious Oxide Coatings

- Ag-Ta-O
  - Sputtered from Ta and Ag targets in reactive oxygen atmosphere
- Exhibit extremely low coefficient of friction at 600 – 700°C

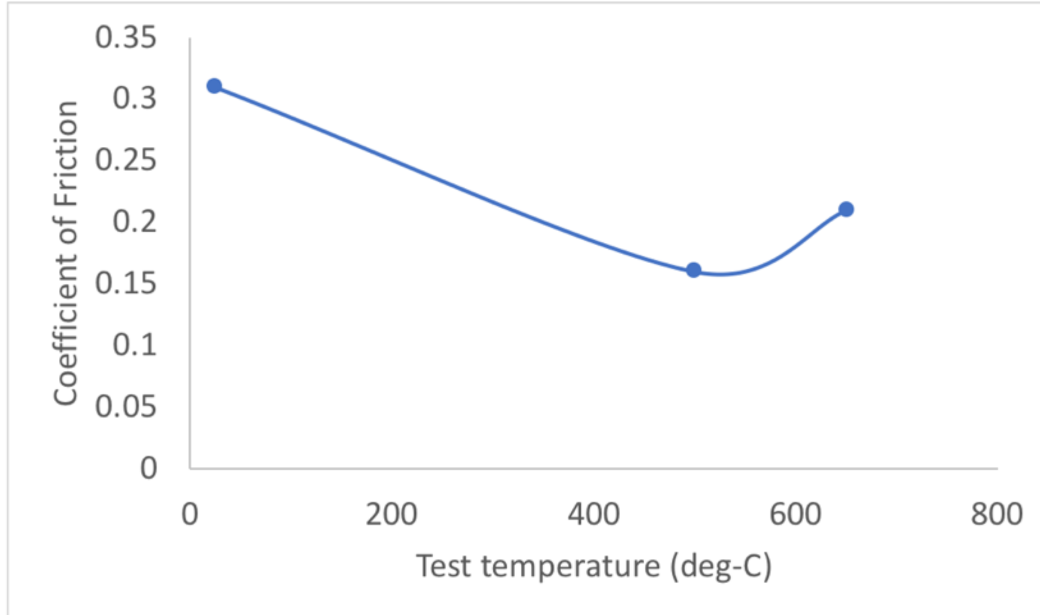


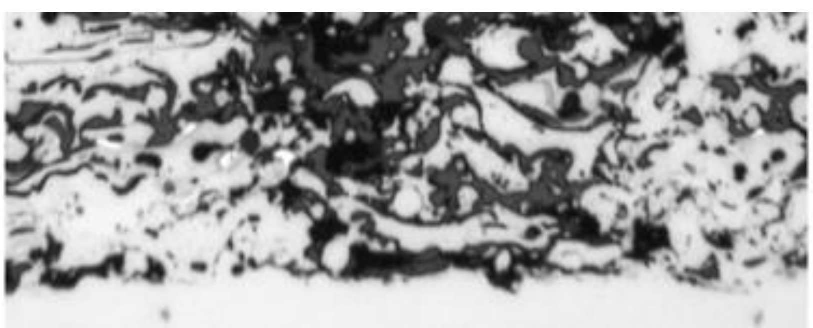
CoF for four silver tantalate coatings

Source: Stone et al., Surf. & Coat. Tech., 2013

NASA Plasma Sprayed Coatings

- PS400
  - Nickel-molybdenum binder for strength
  - Silver and barium–calcium fluoride are added for lubrication
- Has layered microstructure





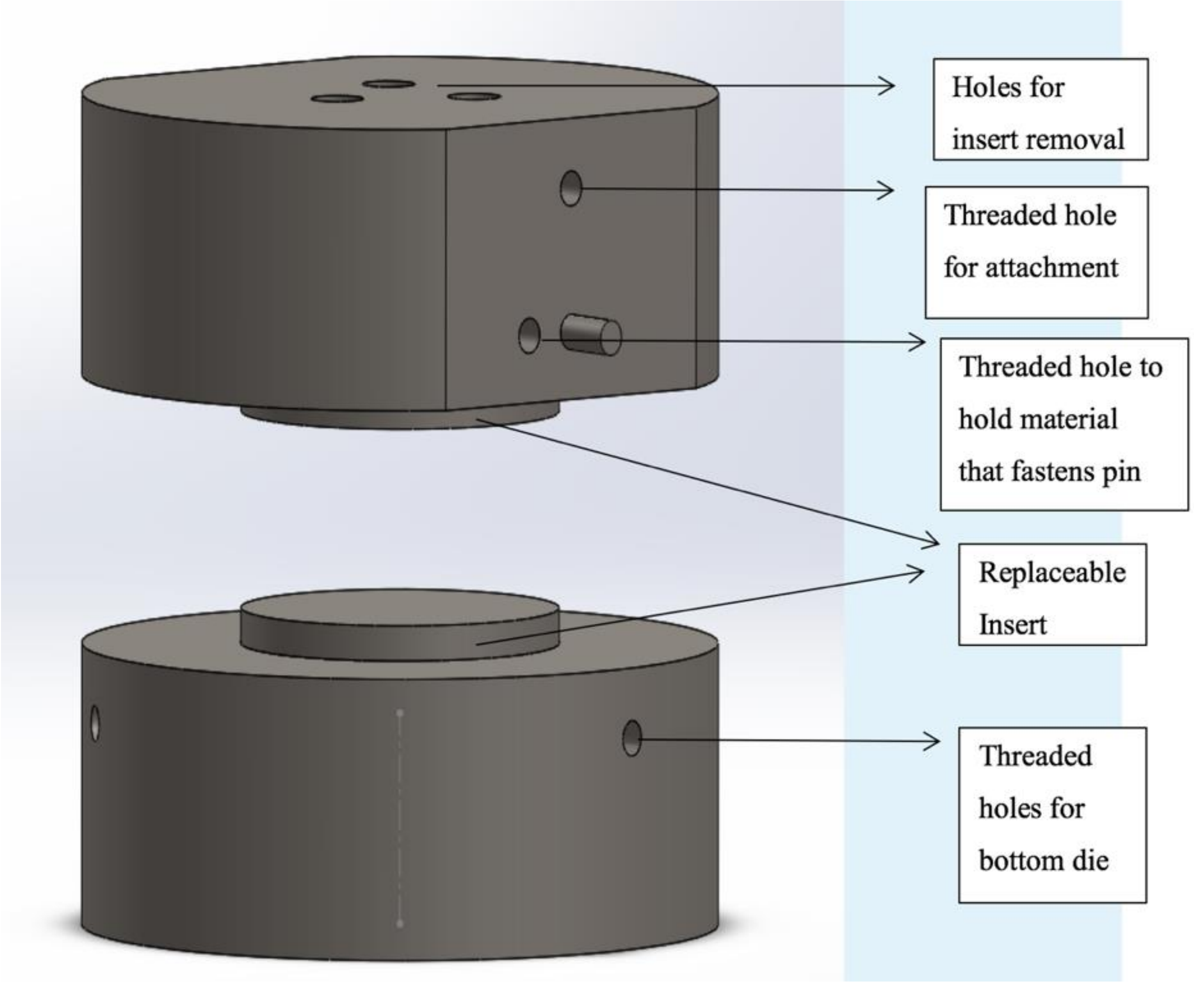
Source: DellaCorte & Edmonds, NASA Report, 2009

Coatings Planning to Evaluate

Type of Coating	Specifics	Supplier	Temperature
Single-layer hard coatings	TiCN	Tribologix, Dayton, Ionbond	<400°C
Multi-layer hard coatings	Ti-MoS_2 (MOST)	Teer in UK, Ionbond	<350°C
	AlCrN-MoS_2	Tribologix	
	TiCN-TiMoS_2	Teer	
	CrN-DLC	Phygen	<300 °C
	CrN-SiC	Phygen	
	i-Kote	Tribologix	350°C
Noble Metals	Hard coating plus noble metal	Voevodin, Scharf & Samir at UNT	<500°C
Highly lubricious oxide	--	We would have to produce our own coating	
Plasma Sprayed	PS400	NASA	
Laser Textured	Laser texture a TiCN coating	Tribologix/CSM	

Task 2:
Tooling for Laboratory Forging Test

Tooling



- Currently fabricating tooling
  - Six sets of replaceable inserts
- A variety of coatings will be placed on each set of replaceable inserts

Effect of Friction on Shape of Ring

- Aluminum rings will be forged to evaluated coefficient of friction
  - Between ring and coated inserts

6061 aluminum rings

- Left to right
  - Increasing reductions in height
- Top to bottom
  - Increasingly effective lubricants
  - Showing larger increases in inner diameter with lower coefficient of friction

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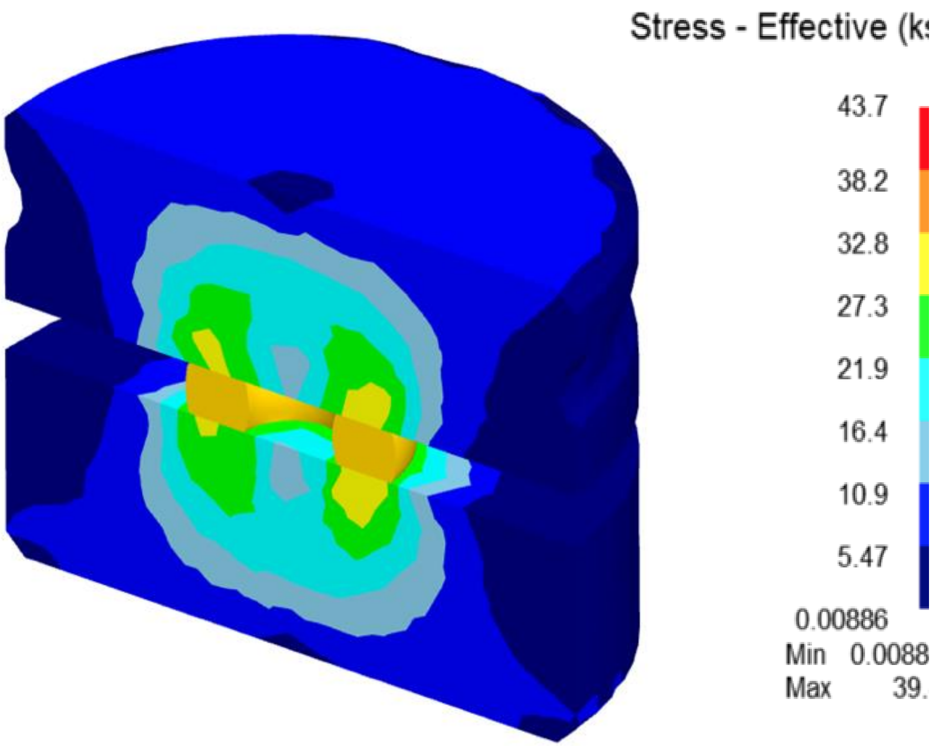
Modeling of Ring Forging Process

- Modeled using DEFORM®
- Highest stress was 32.8 ksi
  - Well below the yield strength of H13 steel
- Plastic deformation of H13 surface should not occur



- Aluminum ring 1" OD, ½" ID
- 0.2 inches per second compression velocity
- Applied to a 100 kip force

Next Steps

Task No.	Task
3	Procure coated die test samples and set up laboratory testing procedure
4	Perform plant trial of best PVD coating identified during laboratory testing
5	Reporting

Questions?

Trever Kehe

tjkehe@mymail.mines.edu

Kester Clarke

kclarke@mines.edu

Steve Midson

smidson@mines.edu