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

Spring 2019 Semi-Annual Meeting
Iowa State University, Ames, IA
April 3-5, 2019

Students: Trevor Kehe, undergraduate student (Mines)
Faculty: Kester Clarke, Steve Midson (Mines)
Industrial Mentor: Rob Mayer (Queen City Forging)
Other Organizations: Forging Industry Educational & Research Foundation (FIERF)

FIERF FORGING FOUNDATION

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

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

- Student: Trevor Kehe (Mines undergraduate)
- Advisor(s): Kester Clarke, Stephen Midson (Mines)

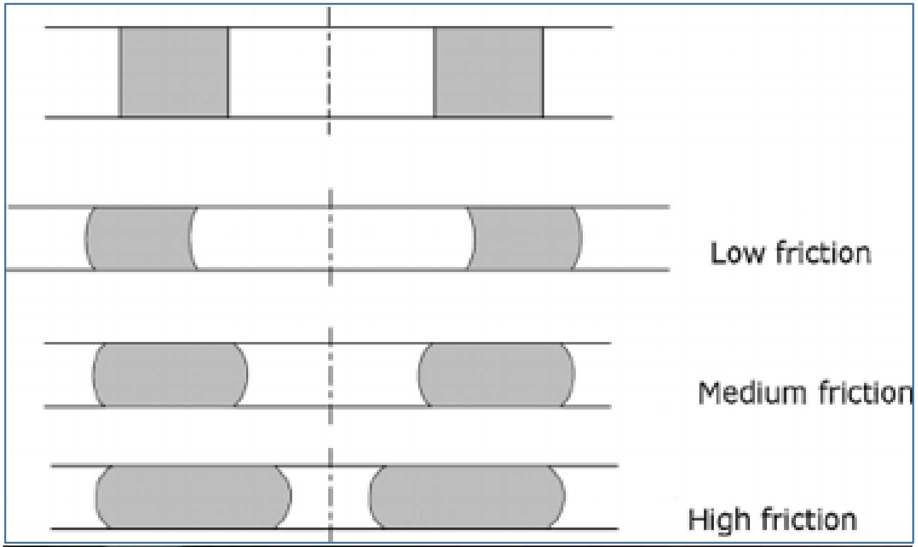
Project Duration
UG: May 2017 to May 2019

- Problem: Forging operations can use significant amounts of lubricant, which can sometimes affect component outcomes and excessive overspray.
- Objective: Evaluate die coatings that can reduce the coefficient of friction of the workpiece to the die.
- Benefit: Reduced lubricant use and greater processing consistency.

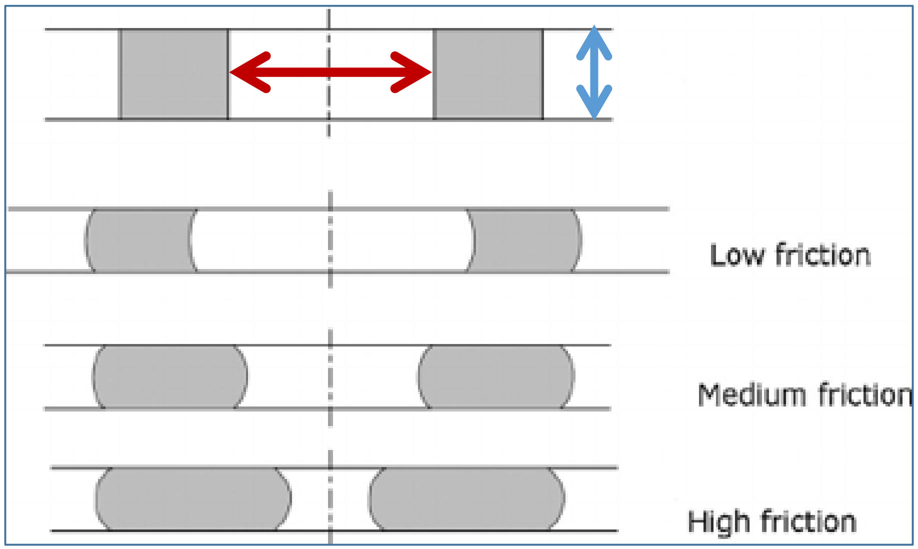
Recent Progress
- Laboratory scale dies with inserts have been designed and manufactured.
- Initial uncoated room and elevated temperature ring-friction tests have been completed.
- Ring-friction tests have been performed on four sets of coated die inserts at room temperature.

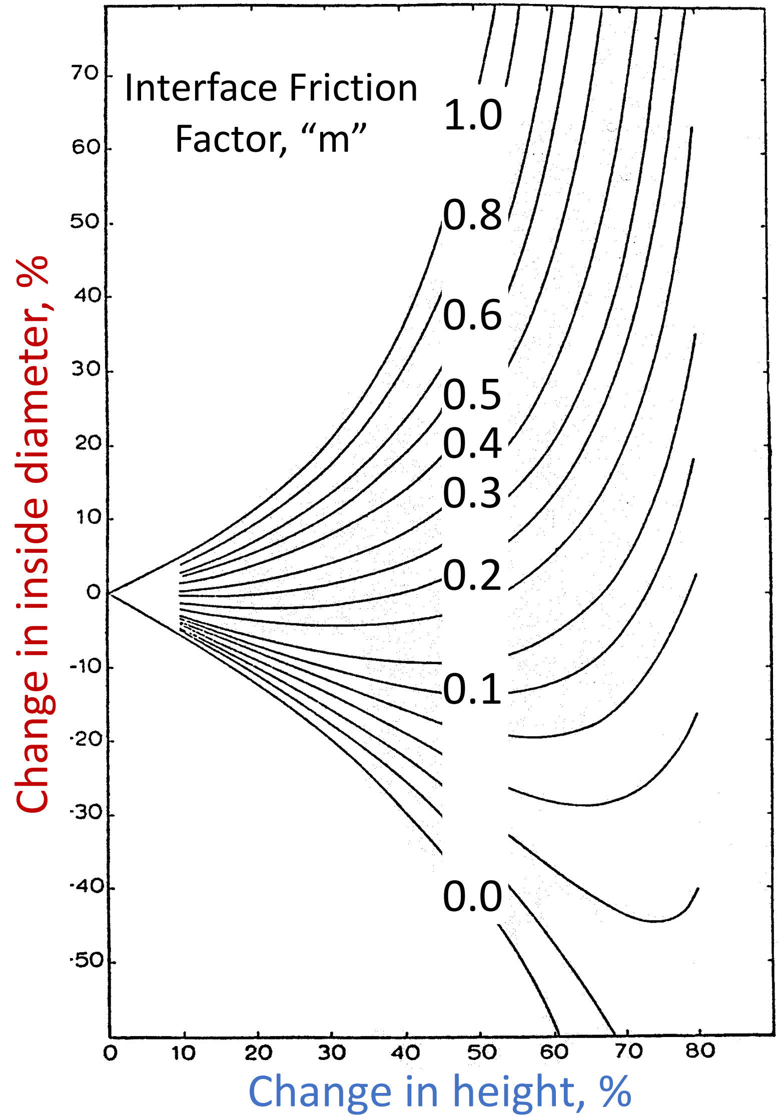
Description	% Complete	Status
1. Literature review	100%	●
2. Die design	100%	●
3. Die manufacture and insert PVD coating	95%	●
4. Ring-friction testing at room and elevated temperatures	75%	●
5. Final report and project summary	40%	●

Ring Friction Test



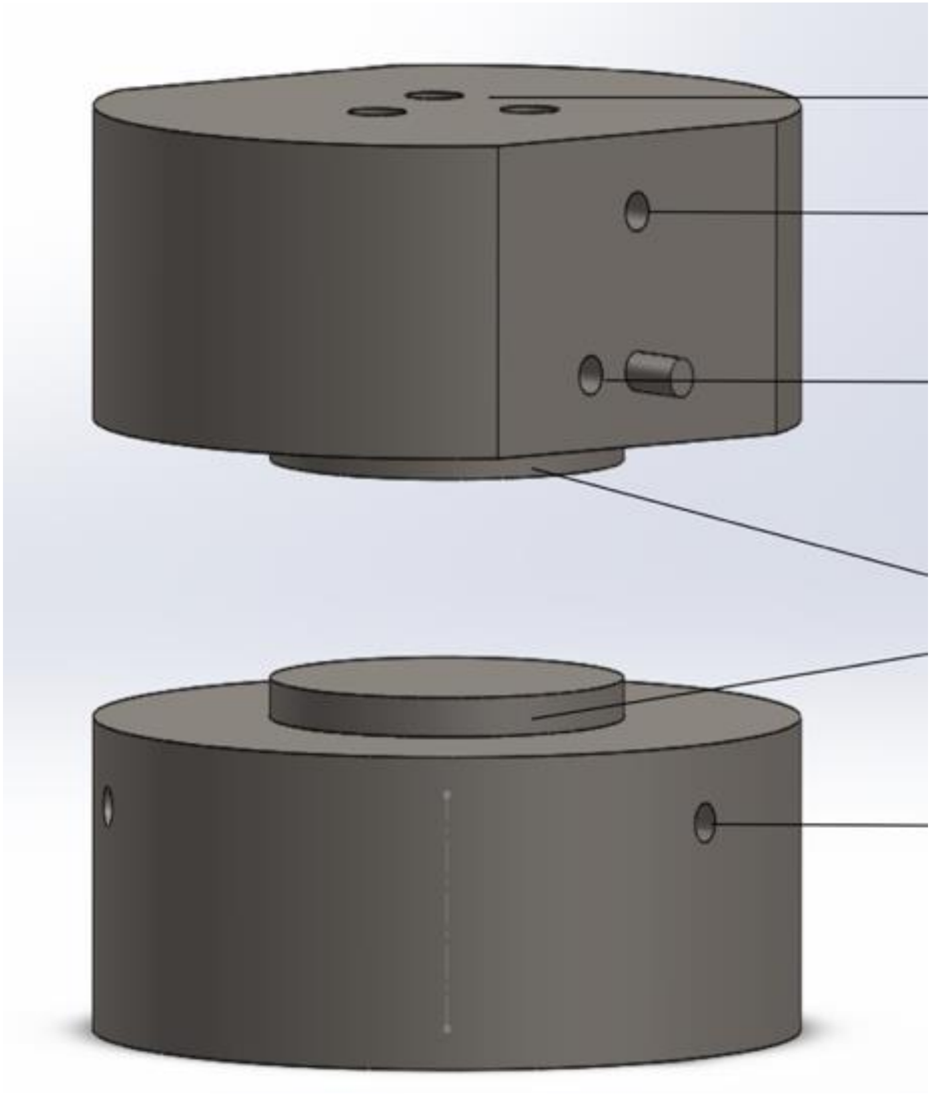
Ring Friction Test



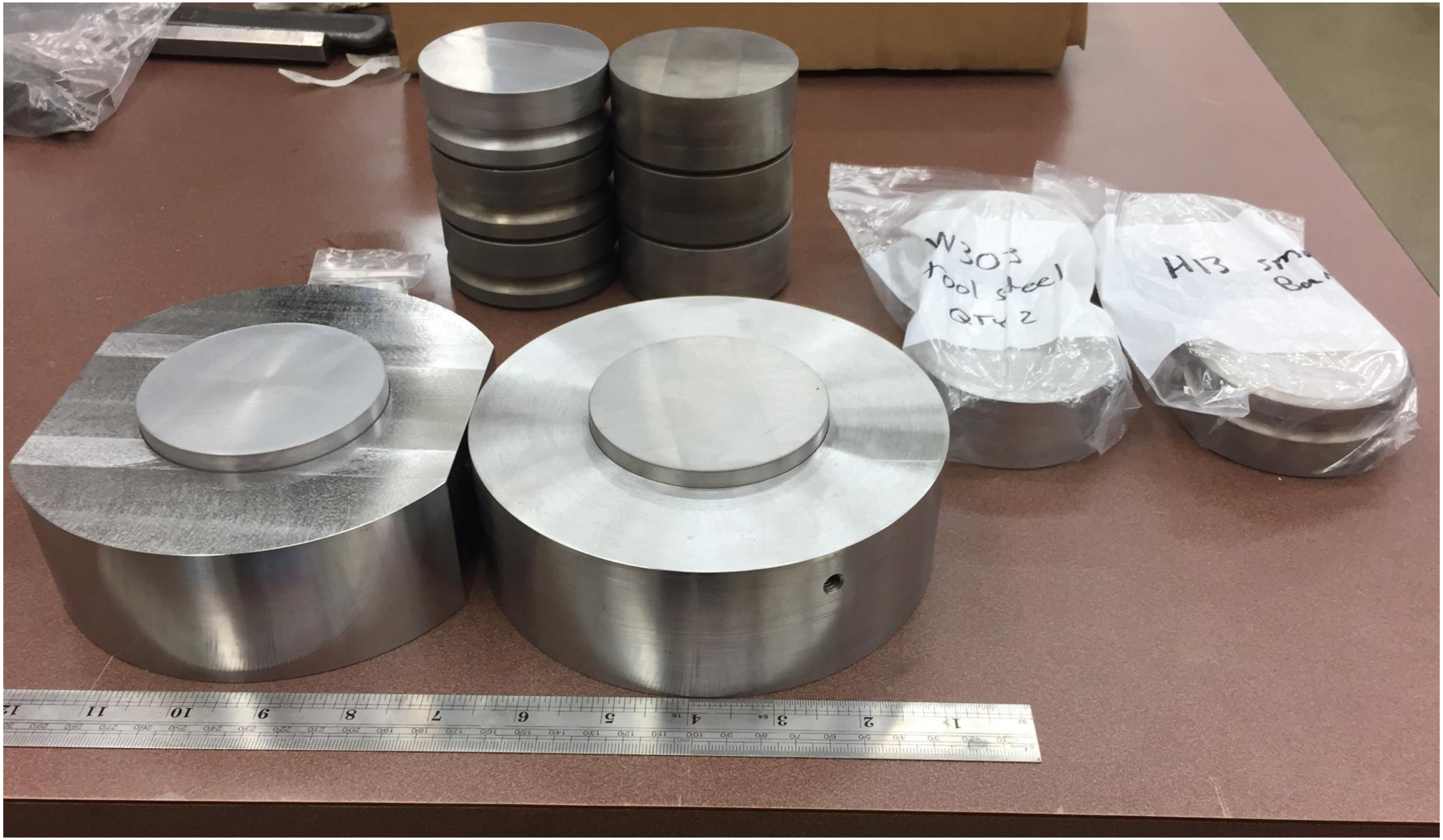


m = interface shear stress/shear yield stress

Die Design and Fabrication



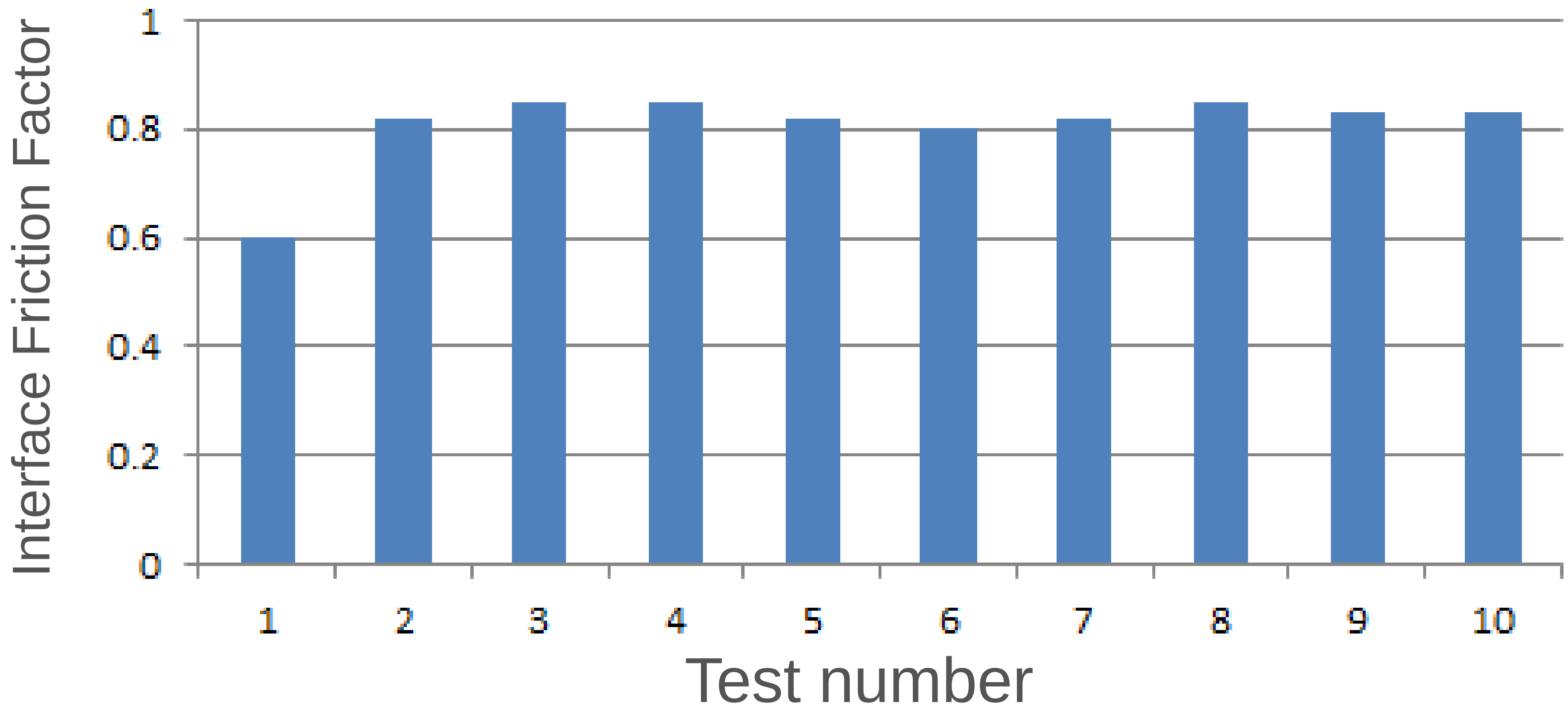
Die Design and Fabrication



Die Design and Fabrication

Measured Friction Factor: Uncoated Inserts, Room Temperature

- Evaluated impact of multiple tests on friction factor
- Controlled surface finish: 1μm diamond polish
- Maximum load: 100 kips (50 tons)



PVD Coatings for Evaluation

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

Type of Coating	Specifics	Supplier	Temperature
Single-layer hard coatings	TiCN	Tribologix, Dayton, Ionbond	<400°C
Multi-layer hard coatings	✓ Super MoS_2	Tribologix	375°C
	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 + etch	Tribologix	350°C
Noble Metals	Hard coating plus noble metal	Voevodin, Scharf & Samir at UNT	<500°C
Highly lubricious oxide	--	None identified	
Plasma Sprayed	PS400	NASA	
Laser Textured	Laser texture a TiCN coating	Tribologix/CSM	

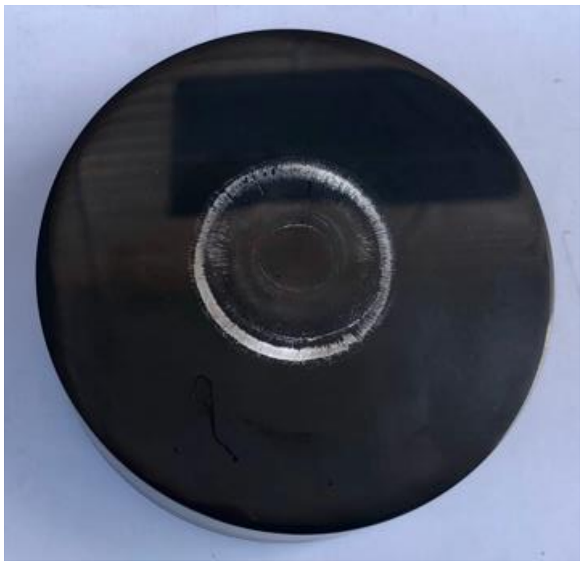
Summary

Coating	Temperature, °C	Lubricant	Friction Factor
None	**Room**	**No lubricant**	**0.80**
None	Room	Graphite	0.30
None	Room	MoS_2	0.12
None	100	MoS_2	0.18
None	200	MoS_2	0.38
i-Kote (350°C)	**Room**	**No lubricant**	**0.35**
Super MoS_2 (375°C)	**Room**	**No lubricant**	**0.60**
CrN-SiC (300°C)	Room	No lubricant	1.00
CrN-SiC	Room	Graphite	0.50
CrN-SiC	Room	MoS_2	0.30
CrN-DLC (300°C)	Room	No lubricant	1.00
CrN-DLC	Room	Graphite	0.40
CrN-DLC	Room	MoS_2	0.30

Al Transfer to Die Surface

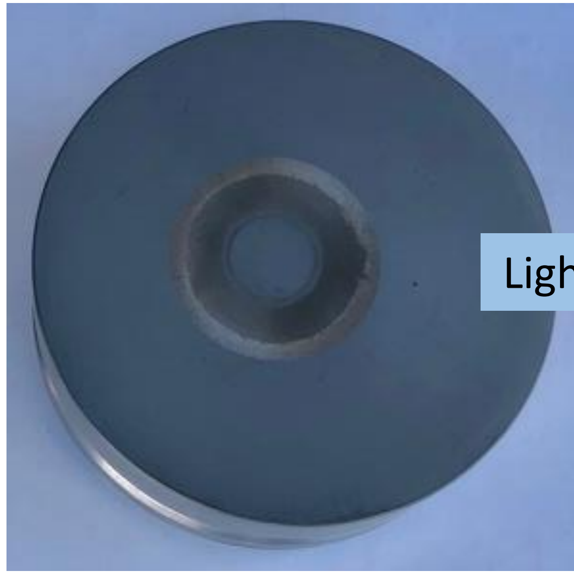
CANFSA
CENTER FOR ADVANCED
NON-FERROUS STRUCTURAL ALLOYS

1 inch

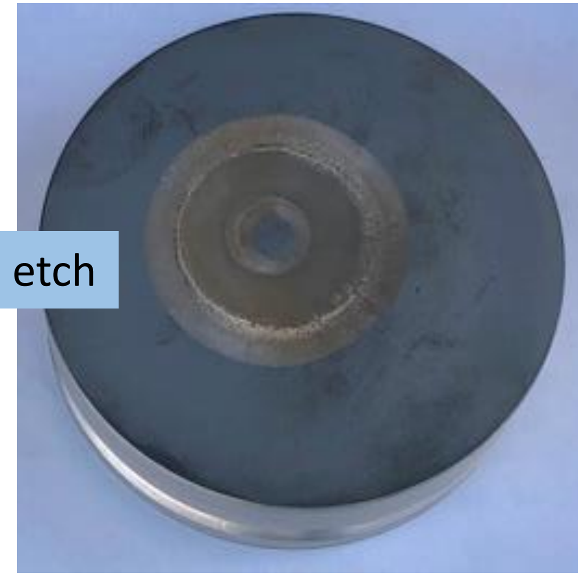


CrN-DLC, 3 Tests

Light etch



i-Kote, 1 Test

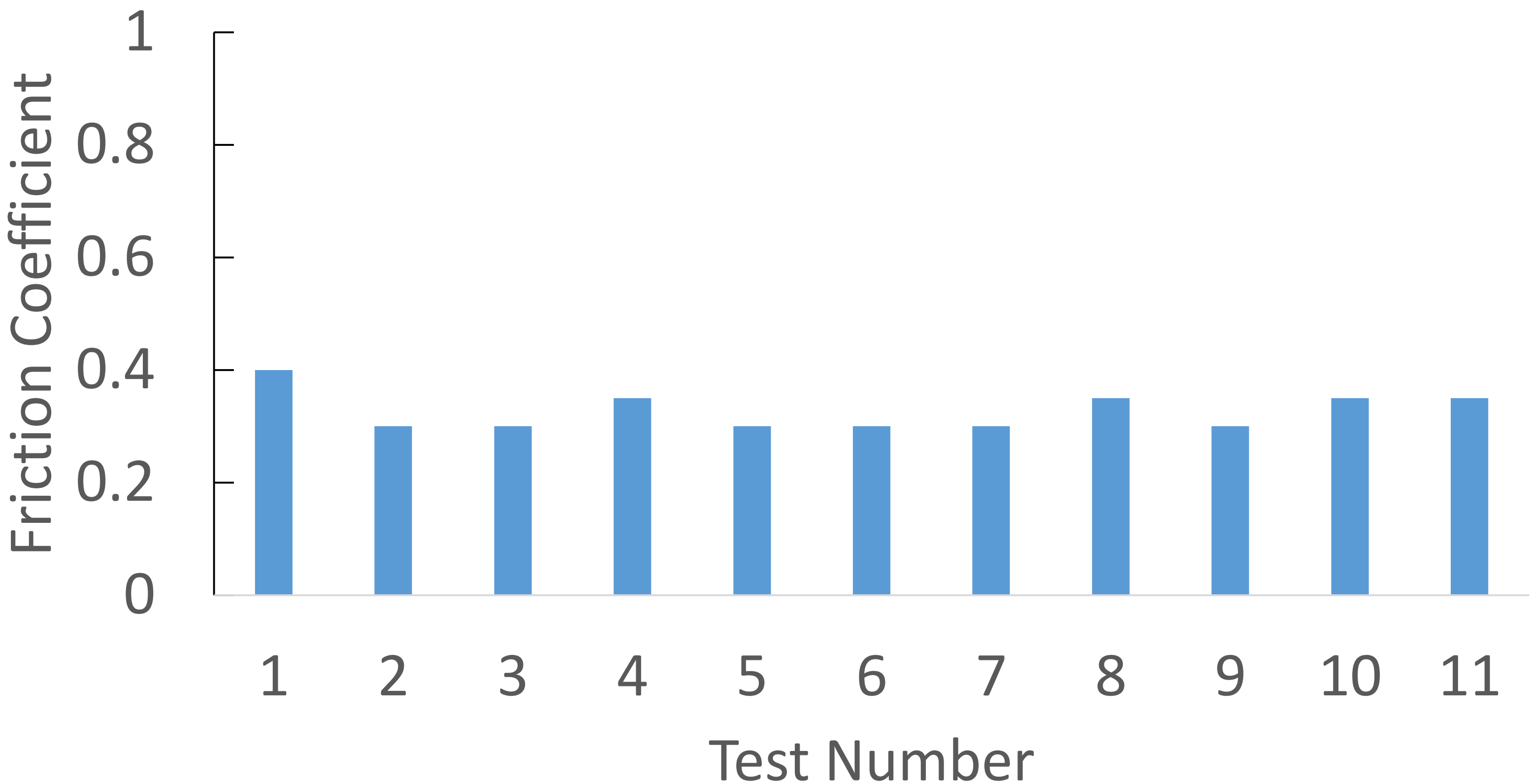


i-Kote, 11 Tests

Heavy etch

Measured Friction Factor

- Die inserts coated with i-Kote
  - No lubricant, room temperature
- No change in friction factor over 11 consecutive forged samples: average interface friction factor of 0.33



i-Kote

- i-Kote was developed for friction applications in space
  - Produced by Tribologix in Golden, CO
- It is a "chameleon coating"
  - Changes performance based on operating conditions
- Contains various nano-sized solid lubricating particles
- Operational temperature up to about 350°C

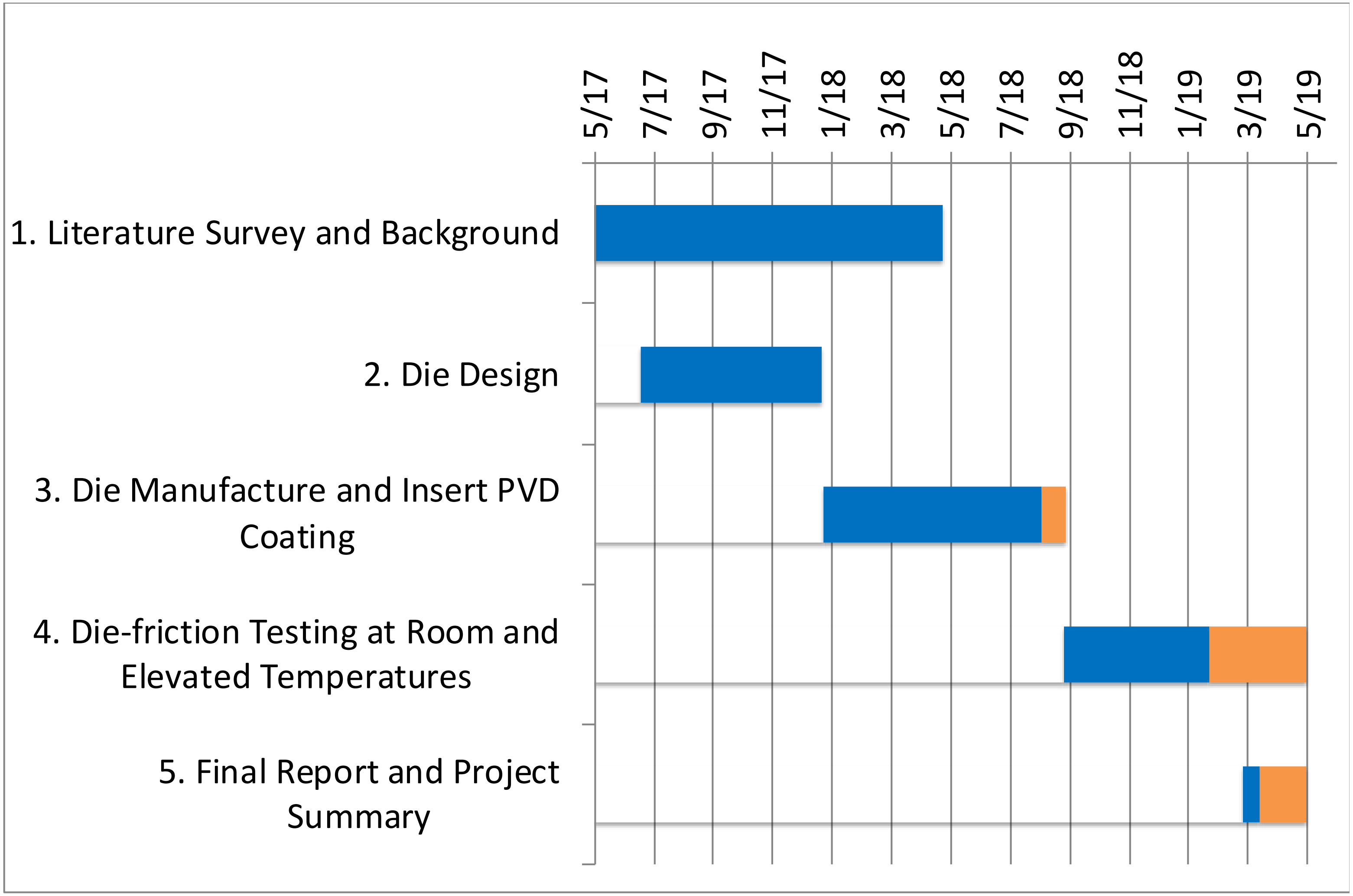
Summary

- Ring-test tooling has been designed and built
  - 6 sets of interchangeable die inserts
  - Temperatures up to 400°C
- Ring-compression friction tests performed
  - No lubricant
  - Graphite
  - MoS_2
- Four coatings evaluated to date
  - SiC and DLC had no effect on friction
  - i-Kote and Super MoS_2 reduced friction factor without lubrication at room temperature

Future Work

- Test the i-Kote and Super MoS_2 coatings at elevated temperatures
  - 100°C
  - 200°C
- Obtain and test a set of die inserts coated with TiCN
- Produce report for FIERF
- Longer term
  - Light-etch i-Kote appeared better than H-etch i-Kote
  - Examine the impact on friction factor of an upper and lower die set coated with light-etch i-Kote

Progress


5/17
7/17
9/17
11/17
1/18
3/18
5/18
7/18
9/18
11/18
1/19
3/19
5/19
1. Literature Survey and Background
2. Die Design
3. Die Manufacture and Insert PVD Coating
4. Die-friction Testing at Room and Elevated Temperatures
5. Final Report and Project Summary

Acknowledgements

- FIERF stage-gated grant, FIERF board
  - "Laboratory Testing to Identify Permanent PVD Coatings to Minimize Lubricants Use During Forging"
  - Stage-gate reviews and guidance
- Die materials
  - Bohler-Uddeholm, Hitachi, Finkl
- Coatings
  - Phygen, Tribologix
- NSF REU program

Trevor Kehe

- Senior in Metallurgical and Materials Engineering, graduating May 2019

Thank you very much!

Trevor Kehe

tjkehe@mines.edu

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

Student: *Trevor Kehe (Undergraduate)*

Faculty: *Kester Clarke, Stephen Midson (Mines)*

Industrial Partners: *QCF, FIERF*

Project Duration: *May 2017 – May 2019*

Achievement

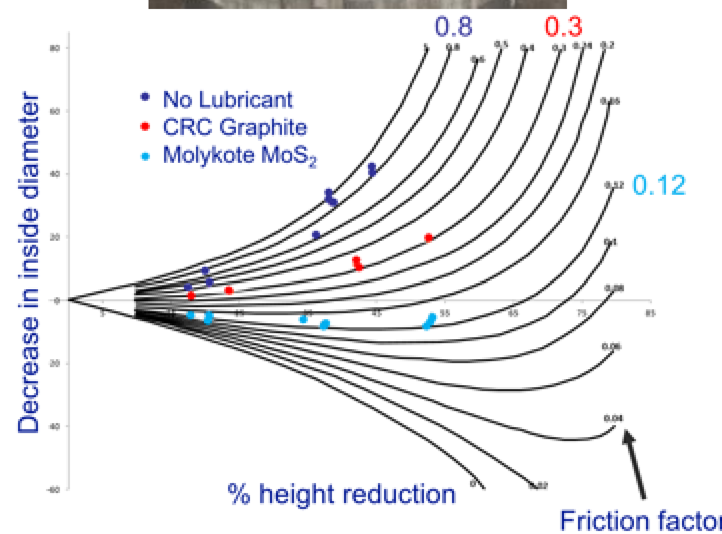
- Developed test methodology to measure friction coefficients during forging at temperatures up to 500°C.

Significance and Impact

- PVD coatings with reduced friction have the potential to reduce the need for lubricant, reduce overspray, and improve cycle times, die life, and quality of forgings.

Research Details

- i-Kote coating significantly reduces coefficient of friction in non-lubricated condition



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

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

Student: *Trevor Kehe (undergraduate)*

Faculty: *Kester Clarke, Stephen Midson*

Industrial Partners: *QCF, FIERF*

Project Duration: *May 2017 – May 2019*

Achievement

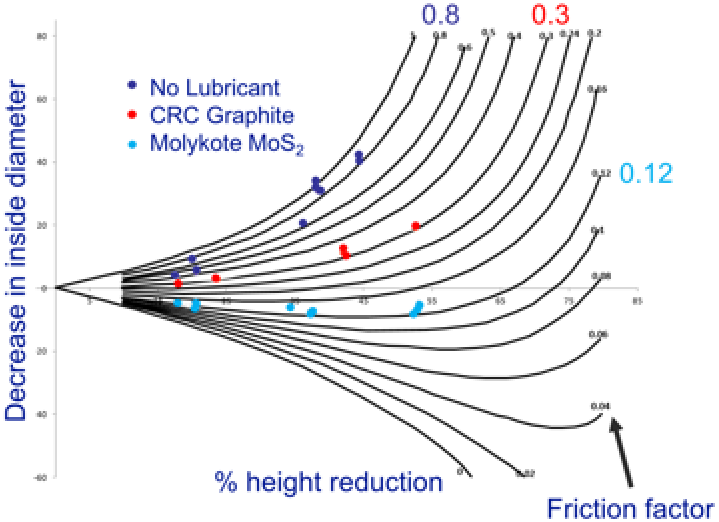
- Developed test methodology to measure friction coefficients during forging up to 500°C.

Significance and Impact

- PVD coatings with reduced friction have the potential to reduce the need for lubricant, reduce overspray, and improve cycle times, die life, and quality of forgings.

Research Details

- i-Kote coating significantly reduces coefficient of friction in non-lubricated condition



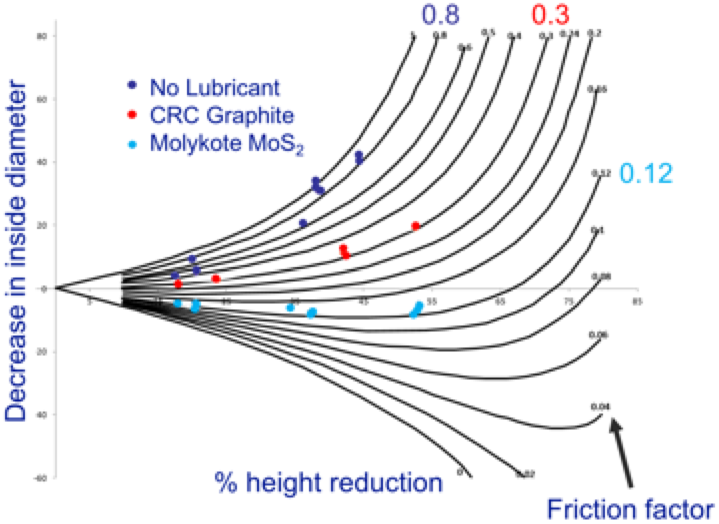
Project 28-L: Laboratory Testing to Identify Permanent PVD Coatings to Minimize Lubricant Use During Forging

Student: *Trevor Kehe (undergraduate)*

Faculty: *Kester Clarke, Stephen Midson*

Industrial Partners: *QCF, FIERF*

Project Duration: *May 2017-May 2019*



Program Goal

- Develop a testing methodology for measurement of friction coefficient during forging, and evaluate effectiveness of PVD coatings.

Approach

- Design and build custom die set to allow forging simulations at temperatures to 500°C.

Benefits

- The potential for reduced lubricant use and greater processing consistency in forging operations.

Industrial Relevance

CANFSA
CENTER FOR ADVANCED
NON-FERROUS STRUCTURAL ALLOYS

Reducing the friction coefficient between die and workpiece in forging may…

…reduce the amount of lubricant required

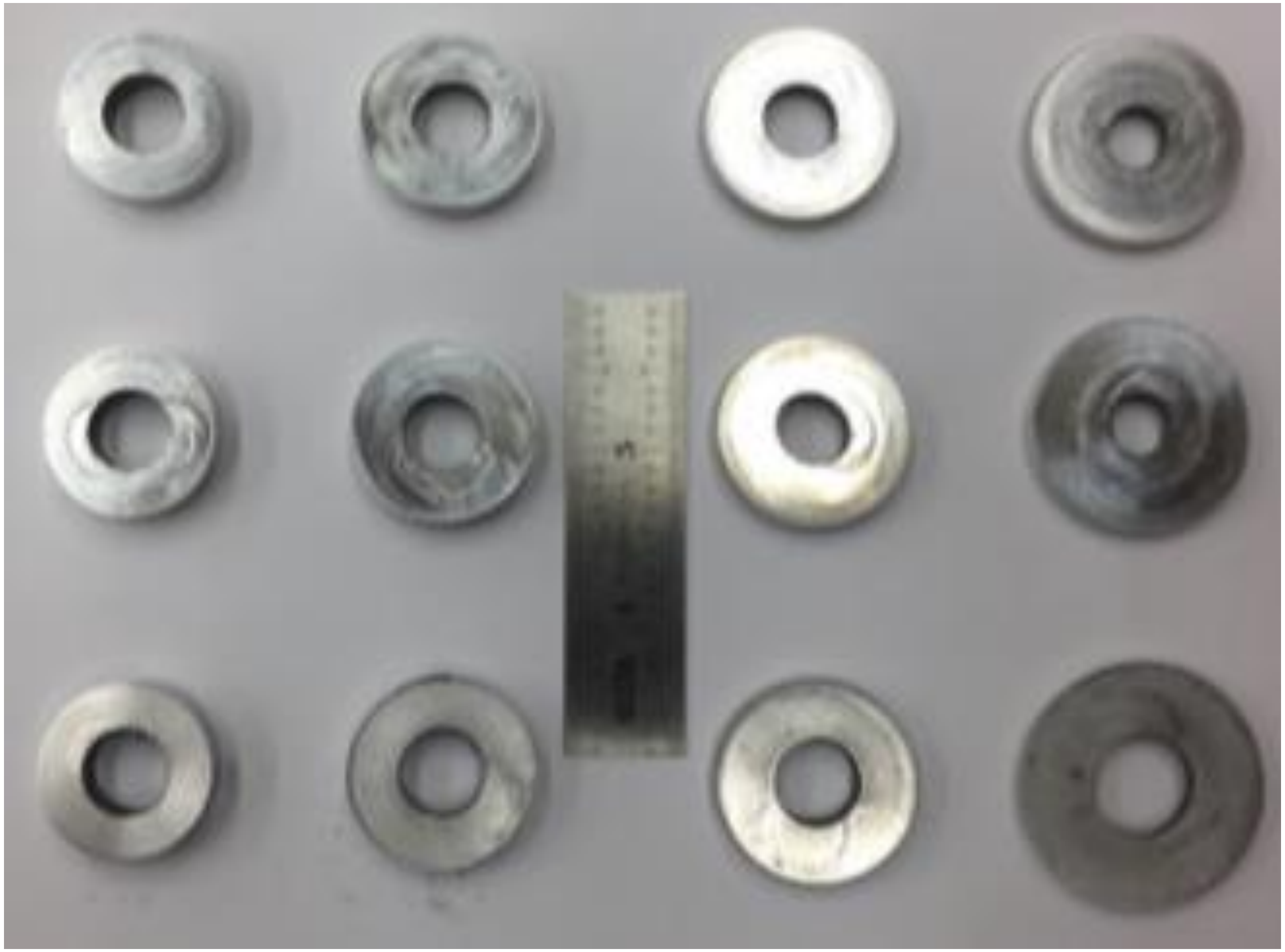
…reduce lubricant overspray

…improve cycle times

…improve die life

…improve quality of forgings

Ring Friction Test: 6061 @ RT



No lubricant

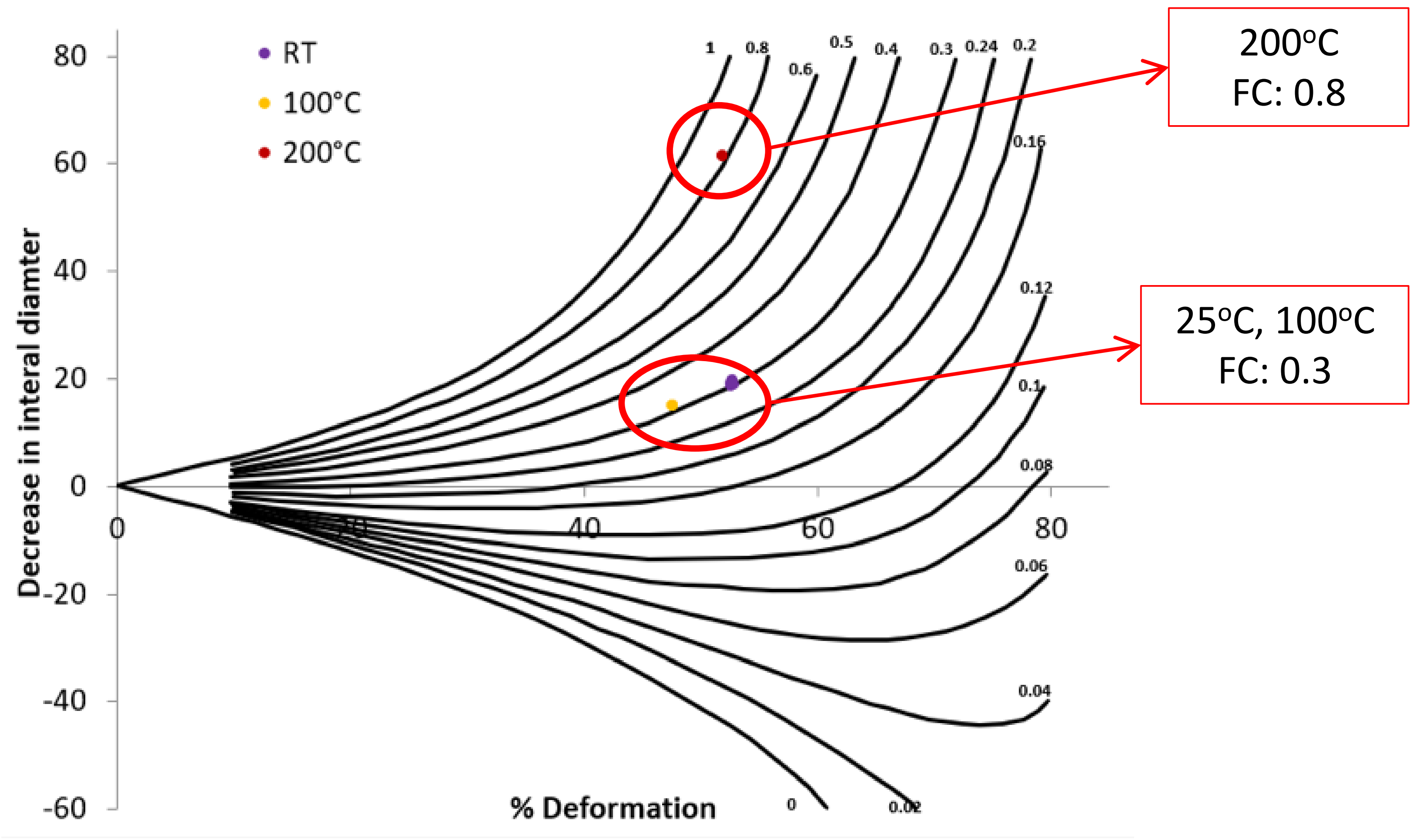
Dry graphite spray

MoS_2 grease

Left to right: Increasing reductions in height

Top to bottom: Increasingly effective lubricants

Measured Friction Coefficient: Uncoated Inserts, Graphite lubricated, Elevated Temperature



Center Proprietary – Terms of CANFSA Membership Agreement Apply

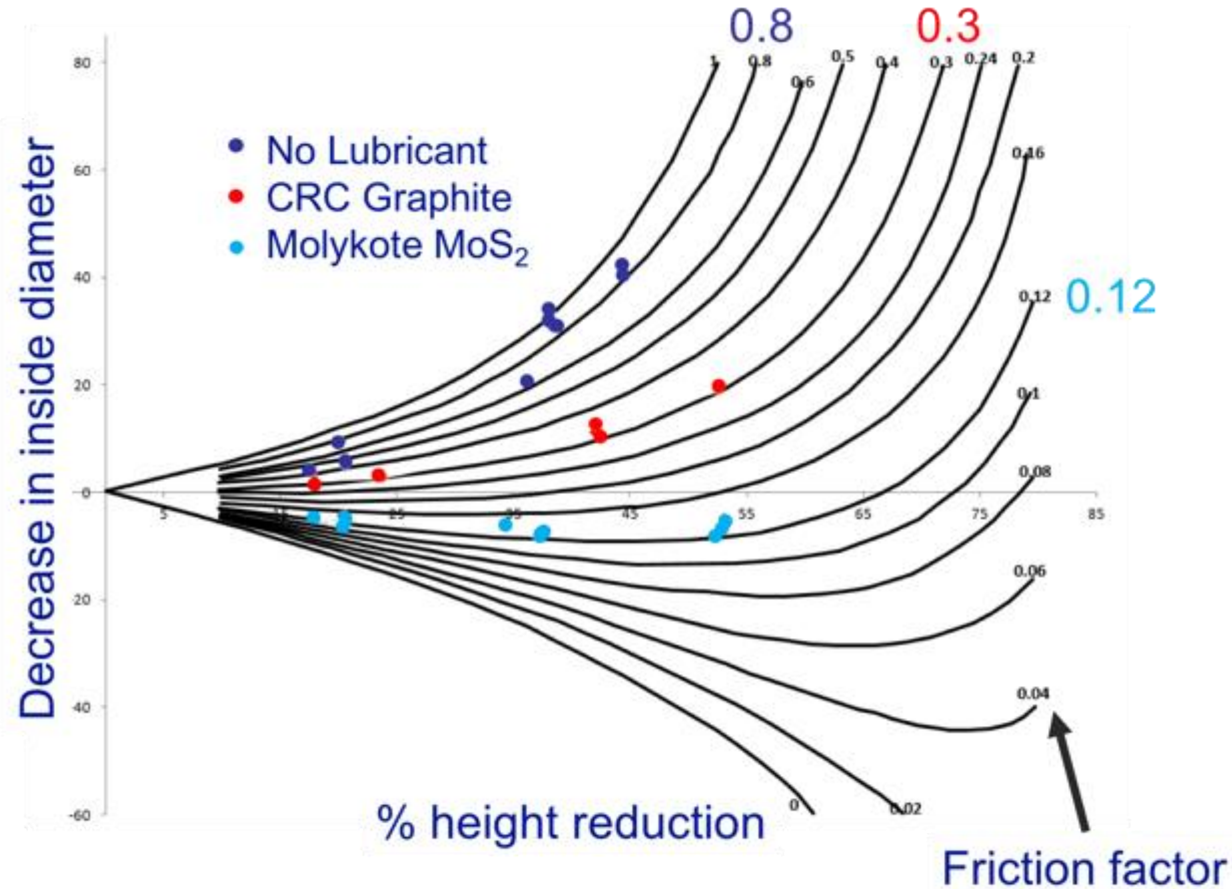
Uncoated Inserts, Room Temperature

Impact of different lubricants

Measured Friction Coefficient: Uncoated Inserts, Room Temperature

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

- Evaluated the impact of different lubricants on friction coefficient



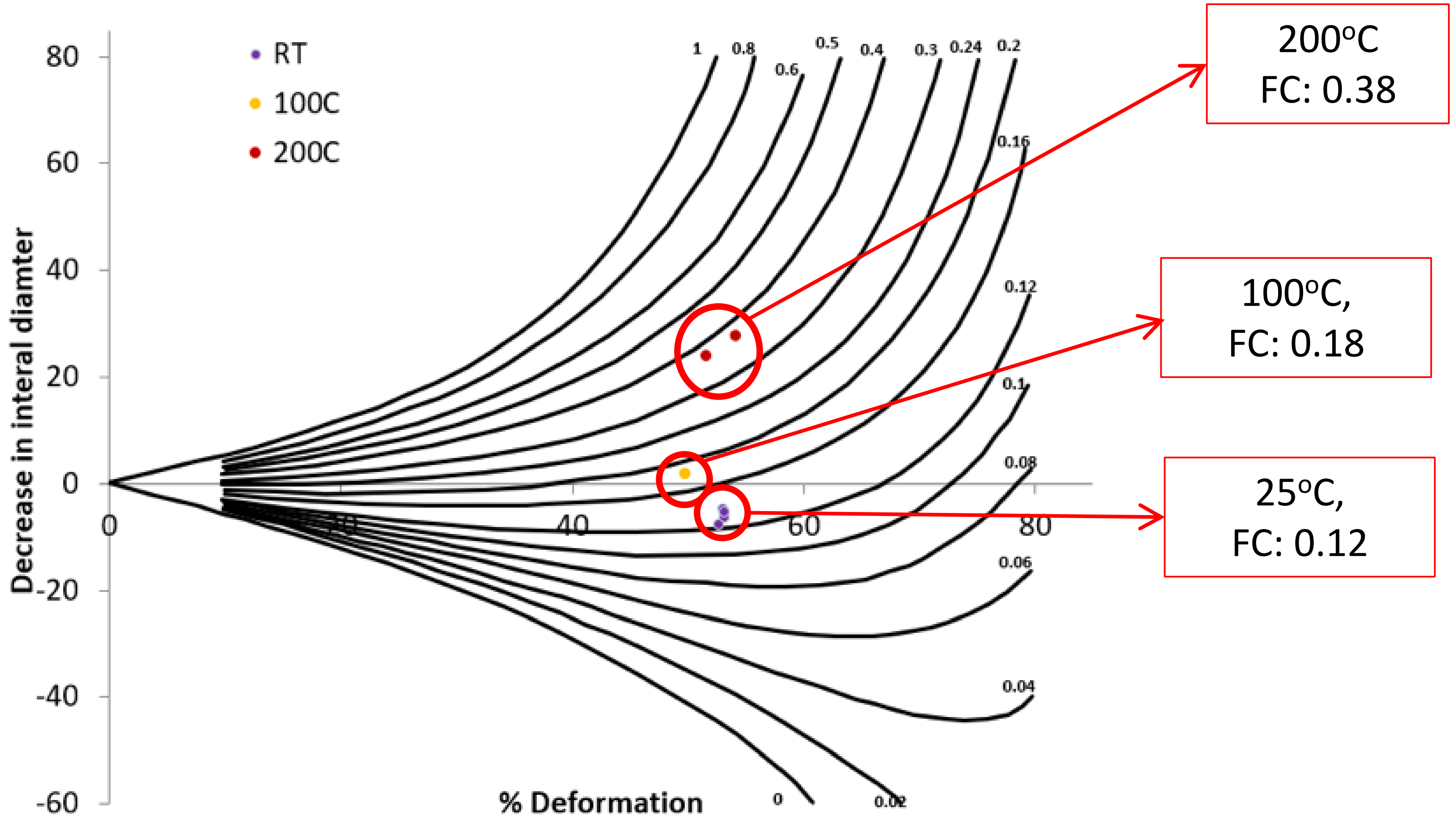
Measured Friction Coefficient: Uncoated Dies, Room Temperature: Summary

Lubricant	Friction Coefficient
MoS_2	0.12
Graphite	0.30
No lubricant	0.80

Uncoated Inserts Lubricated

Impact of testing temperature

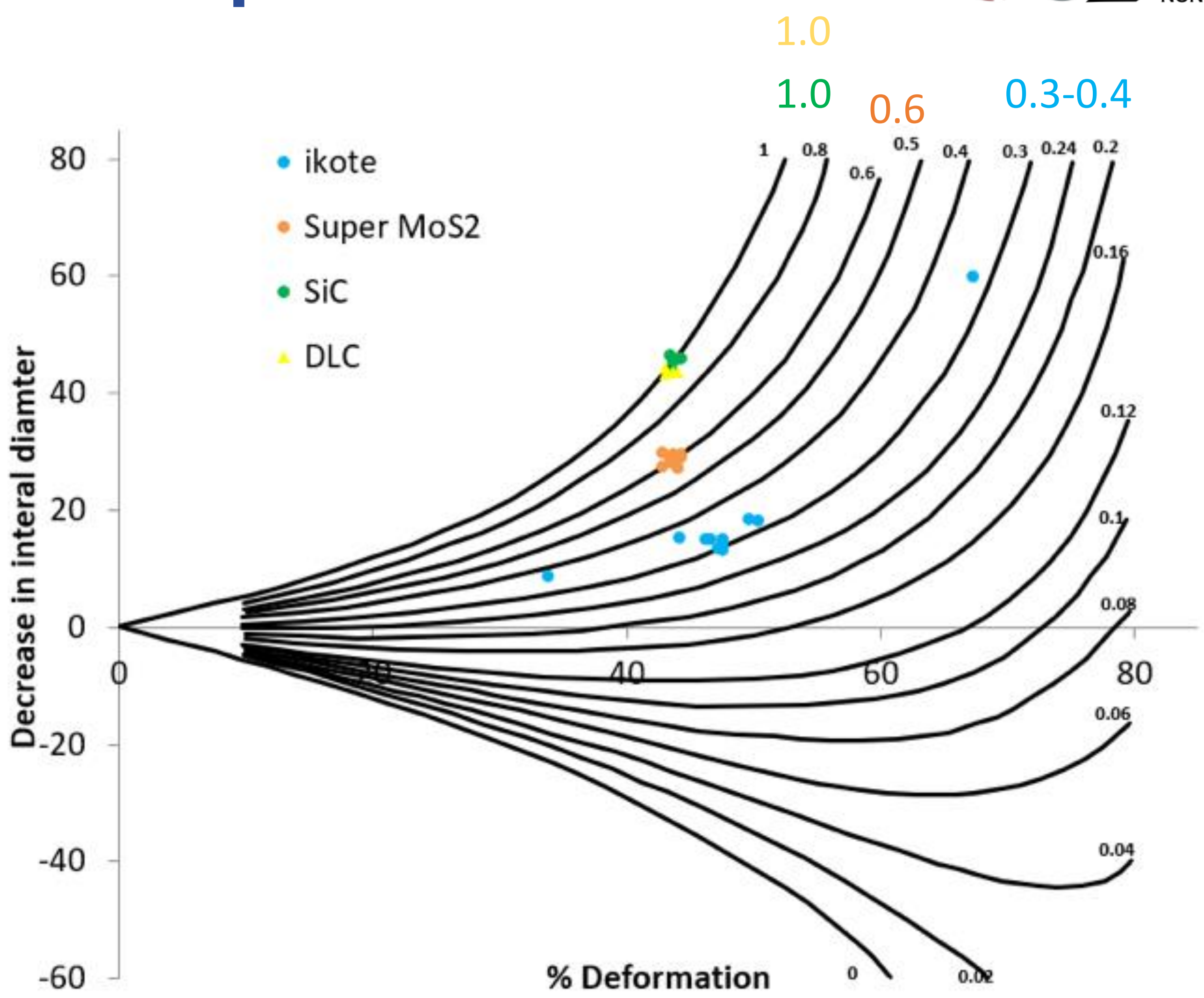
Measured Friction Coefficient: Uncoated Inserts, MoS_2 lubricated, Elevated Temperature



Coated Inserts
No lubricants
Room temperature

Impact of different coatings

Coated Dies, No Lubricant, Room Temperature



Measured Friction Coefficient: Coated Dies, No Lubricant, Room Temperature: Summary

CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS

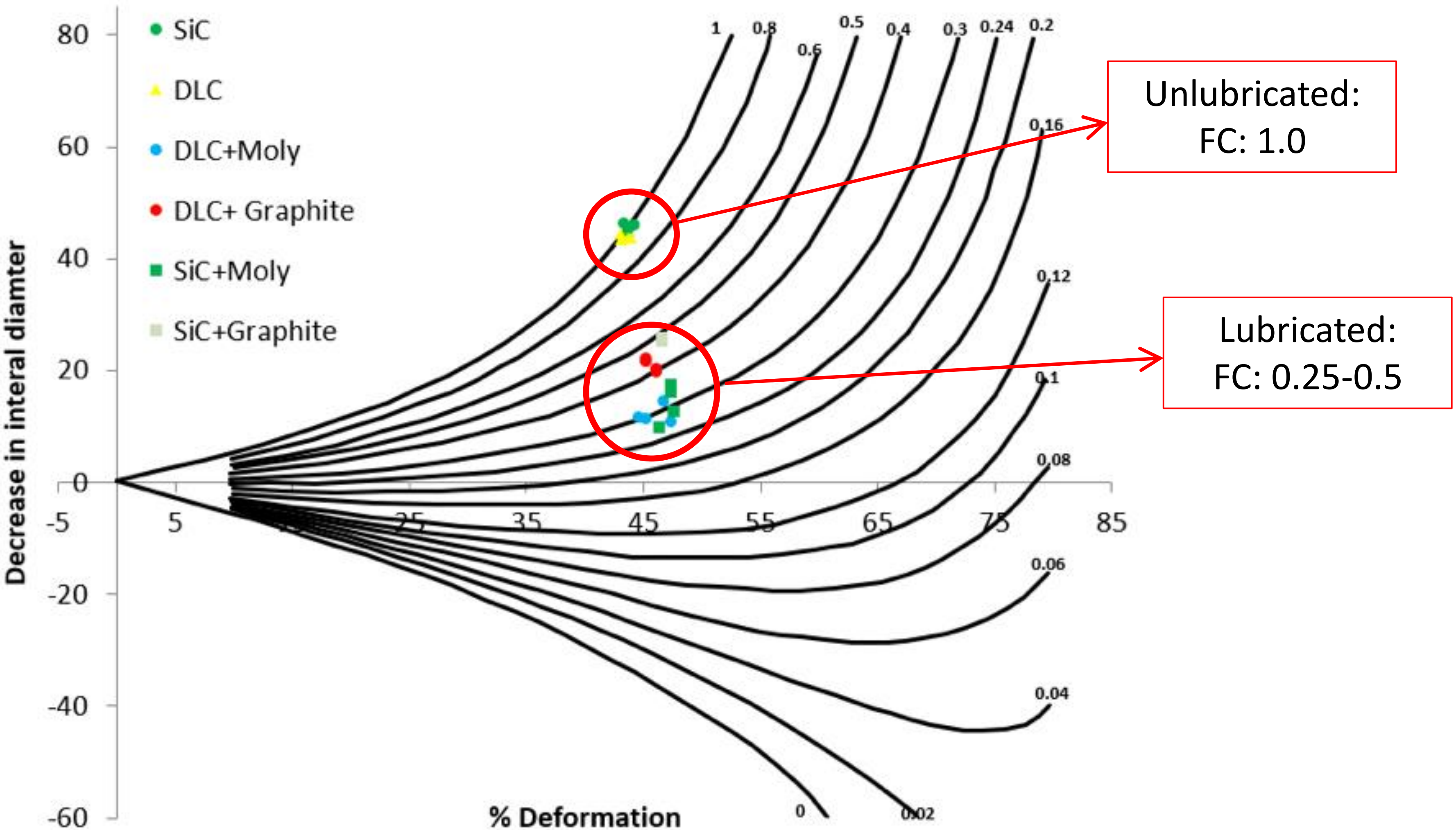
Coating	Friction Coefficient
i-Kote	0.3 – 0.4
Super MoS_2	0.6
SiC	1.0
Diamond like carbon	1.0

Coated Inserts
SiC, DLC Coatings
Room temperature

Lubricated vs. unlubricated

Measured Friction Coefficient: Coated Inserts, Lubricated, Room Temperature

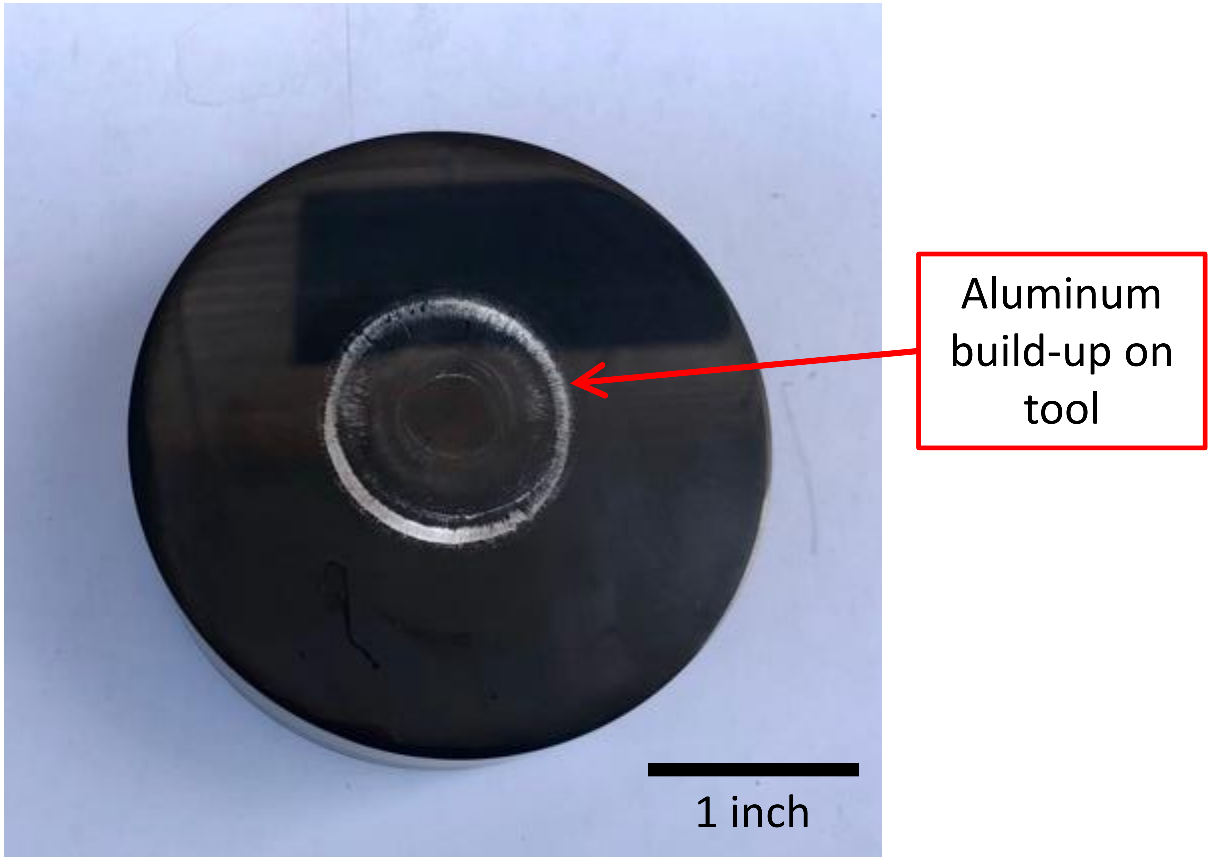
CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS



Uncoated Inserts, Room Temperature

Diamond-Like Carbon (DLC) Coating

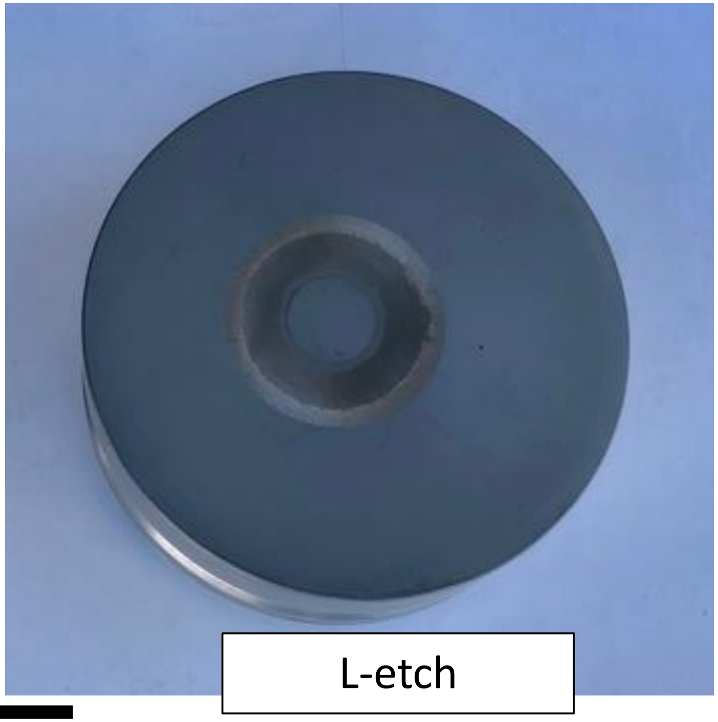
CANFSA
CENTER FOR ADVANCED NON-FERROUS STRUCTURAL ALLOYS



- Uncoated, DLC & SiC coatings showed significant aluminum build-up on tool
  - After only 3 forging trials

i-Kote

- After one forging trial



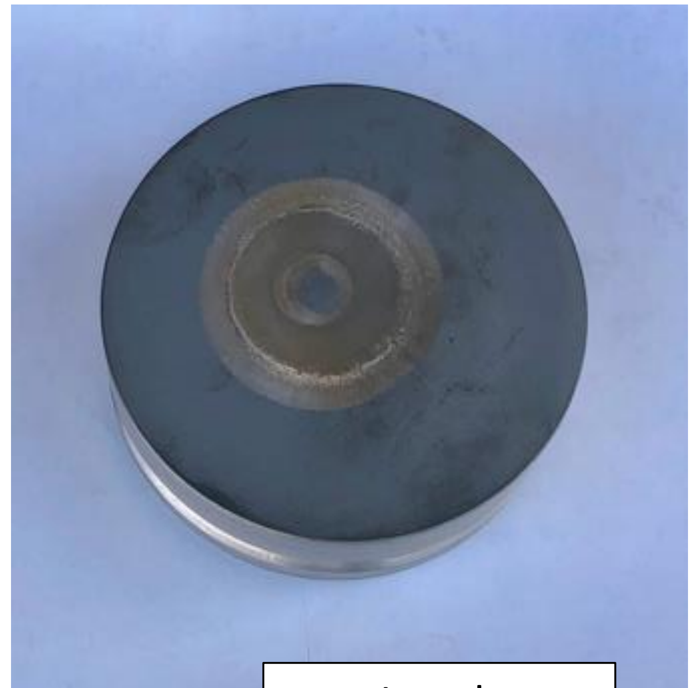
1 inch

- Very little aluminum build-up on tool
  - L-etch appears to be better than H-etch

i-Kote Coating

- After forging 11 samples

H-etch



L-etch

1 inch

- Slightly more aluminum build-up on tool
  - L-etch still much better than H-etch