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

Fall 2018 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 2-4, 2018

Student: Trevor Kehe (Mines)
Faculty: Kester Clarke, Stephen Midson (Mines)
Industrial Mentors: Rob Mayer (Queen City Forge)
Other Participants: Forging Industry Research and Educational Foundation

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

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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 temperature ring-friction tests have been completed.
- Four sets of die inserts have been PVD coated at vendors.

Description	% Complete	Status
1. Literature review	100%	●
2. Die design	100%	●
3. Die manufacture and insert PVD coating	90%	●
4. Ring-friction testing at room and elevated temperatures	35%	●
5. Final report and project summary	15%	●

Industrial Relevance

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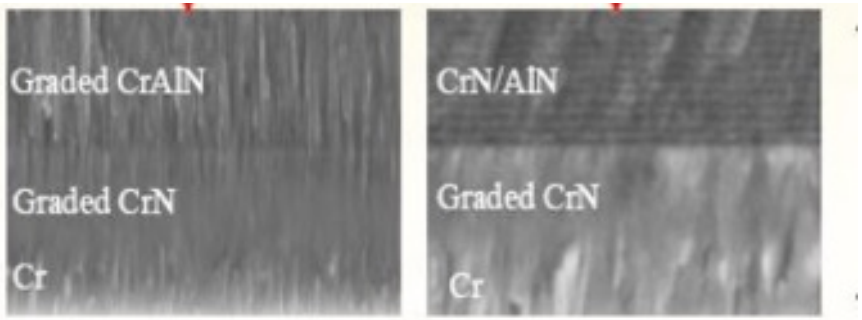
- Reducing the friction coefficient between die and workpiece in forging will:
  - reduce the amount of lubricant required
  - reduce lubricant overspray
  - improve cycle times
  - improve die life
  - improve quality of forgings

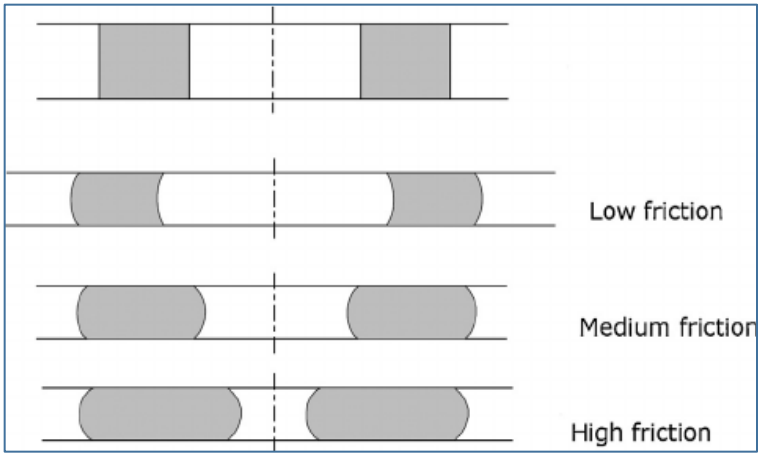
Project approach

- Leverage the recent Mines “Lube Free” die casting coating project
  - New PVD coatings reduced lubricant use significantly
  - Apply similar coating technologies to forging dies



- Develop flexible testing methodology
  - Evaluate relative coefficients of friction of uncoated and PVD coated surfaces
  - Perform tests using aluminum samples at temperatures from ambient to 500°C
  - Investigate effects of lubricant use in combination with PVD coatings

Ring friction test



Ring friction test: 6061 @ RT

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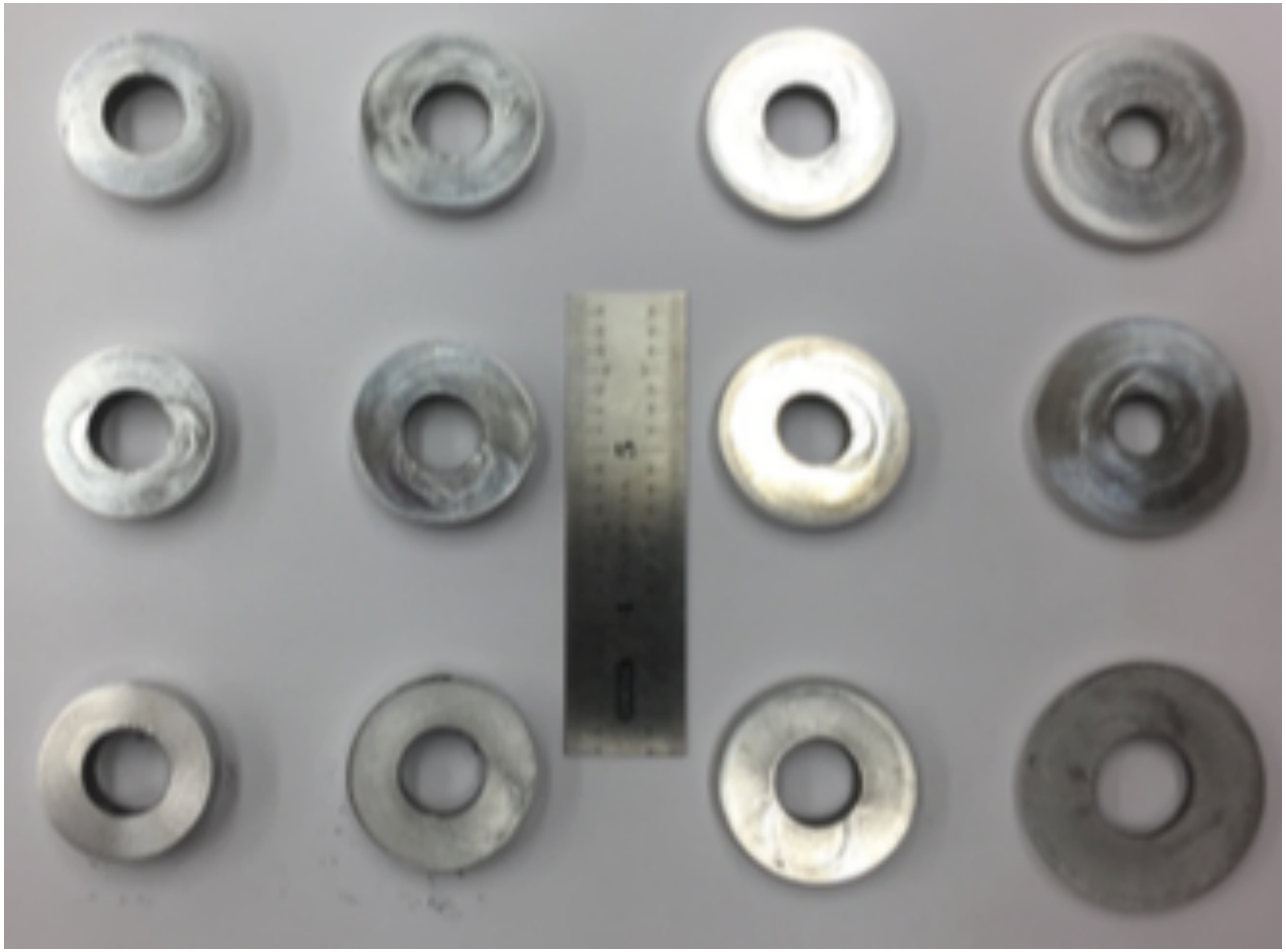


No lubricant

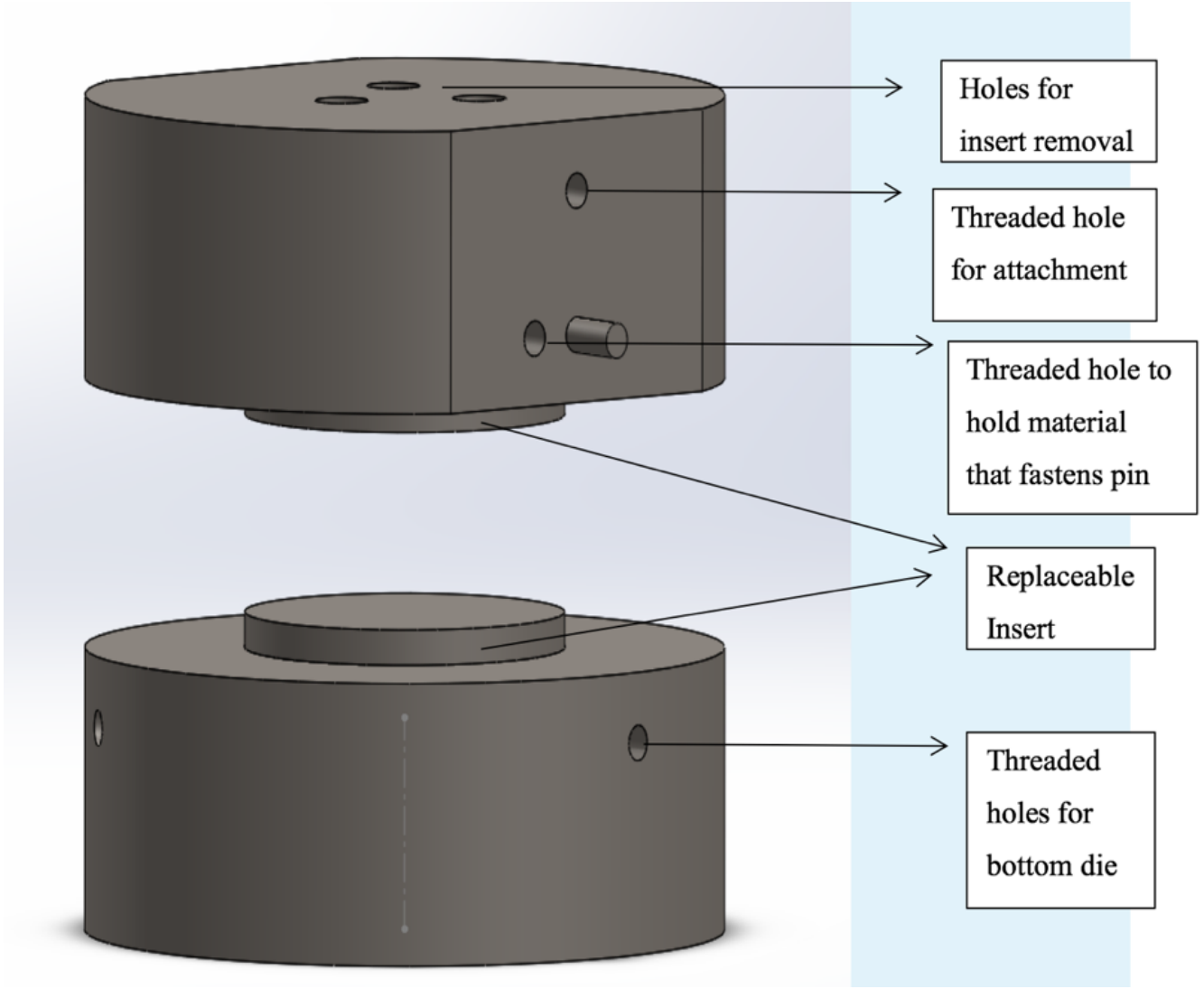
Dry graphite spray

MoS_2 grease

Left to right: Increasing reductions in height

Top to bottom: Increasingly effective lubricants

Die design and fabrication



Die design and fabrication

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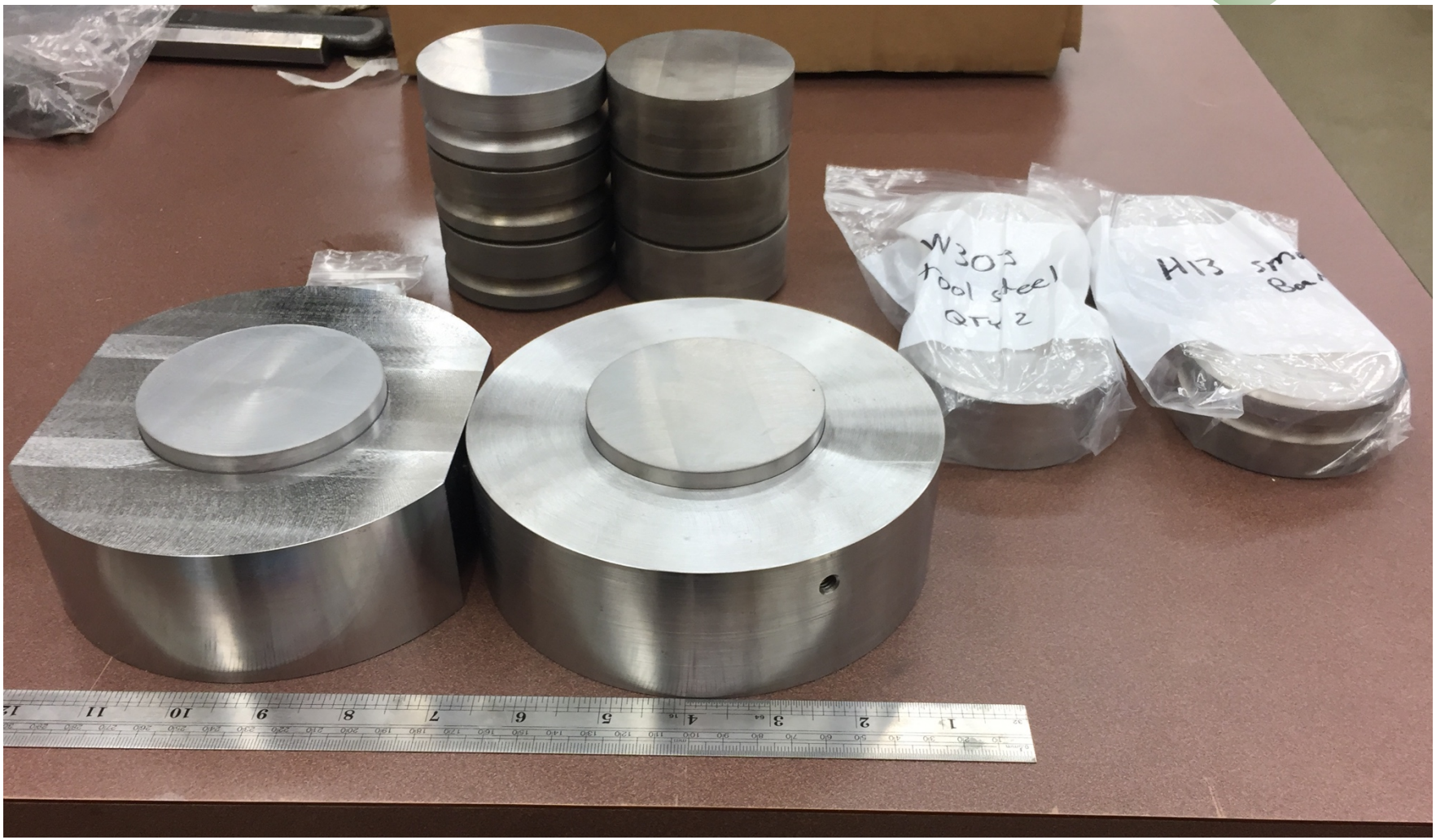
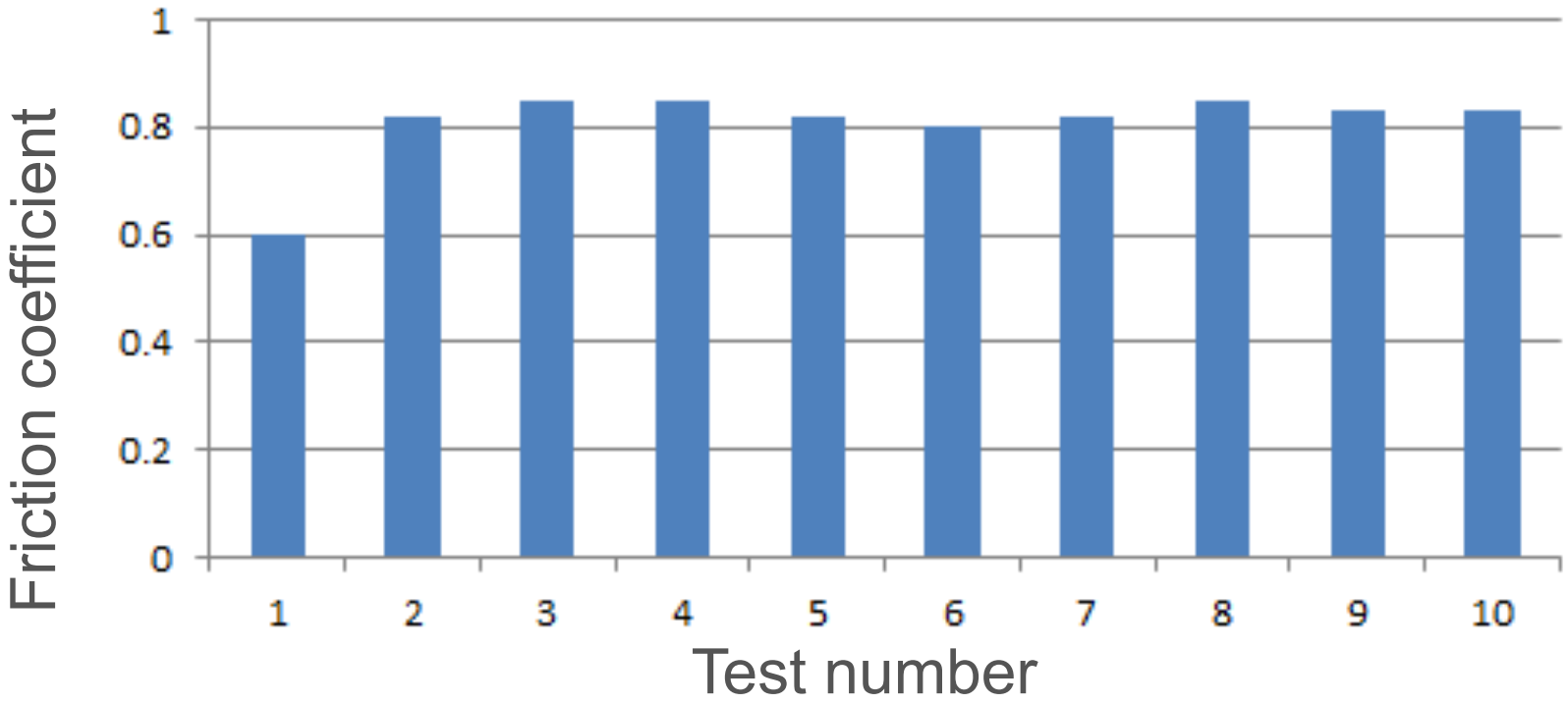


Measured friction coefficient

- Die inserts polished to 1µm diamond to normalize surface topology
- Measured friction coefficient over multiple tests
  - No lubricant, room temperature, uncoated dies, 6061 samples



Measured friction coefficient, room temperature

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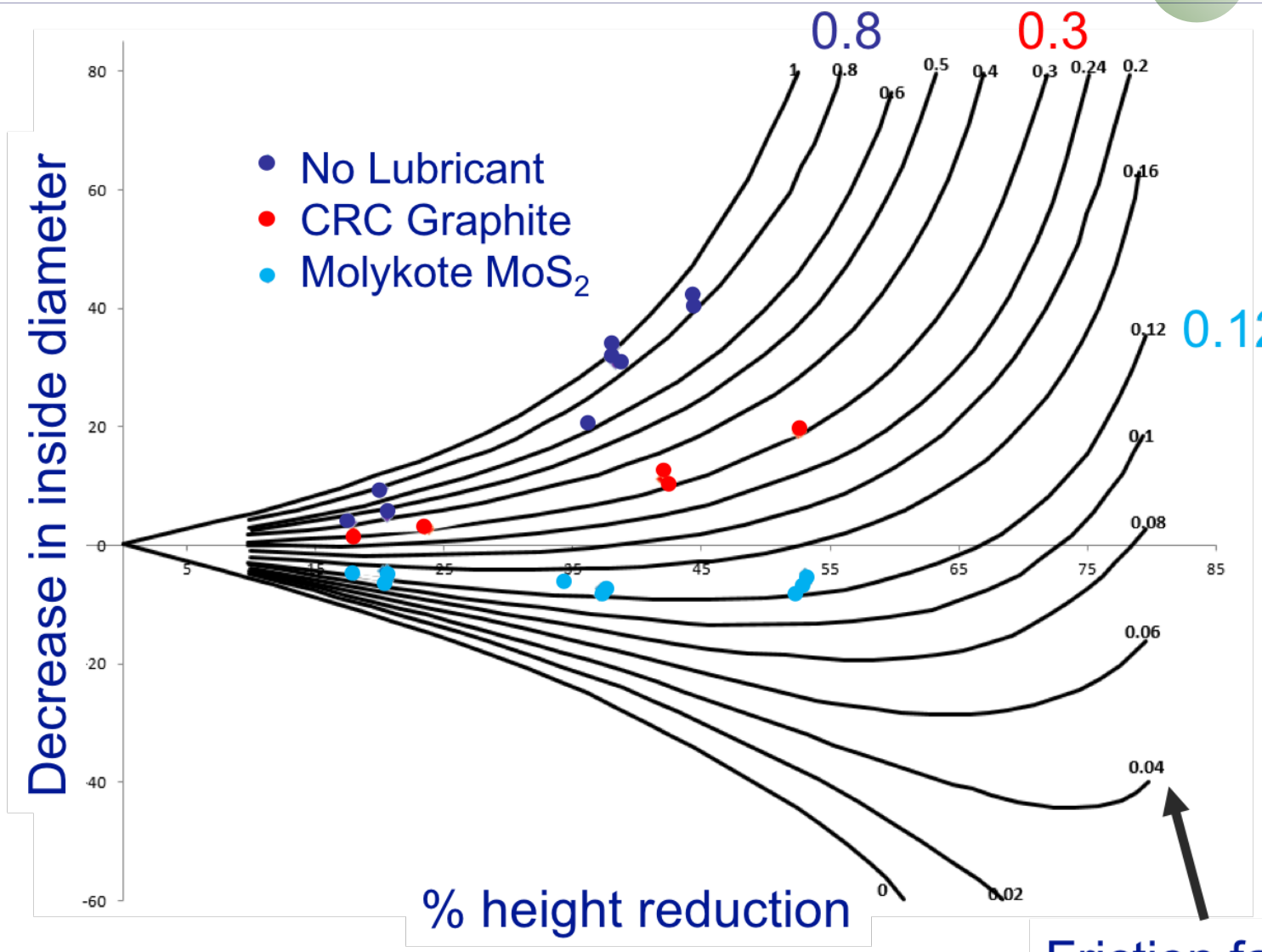

PVD coatings

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- 6 die sets (uppers + lowers)
  - 1 H13 set used for no-coating baseline
  - 4 H13 sets are at vendors for coating
    - Can be re-coated
    - Surface imaging, tribology, and metallographic examination of coating performance also possible
  - 1 W303 set will be used to validate no-coating baseline values and coating effectiveness on a different substrate

PVD coatings

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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	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	

PVD Coating test matrix

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- Measure coefficient of friction on uncoated dies and four initial PVD coatings selected (5)
- Vary temperature from ambient to 300°C (4)
- Test with and without lubricant (3)
  - Graphite spray
  - MoS_2 grease
- Three sets of duplicate rings at three deformation levels (9)

Summary

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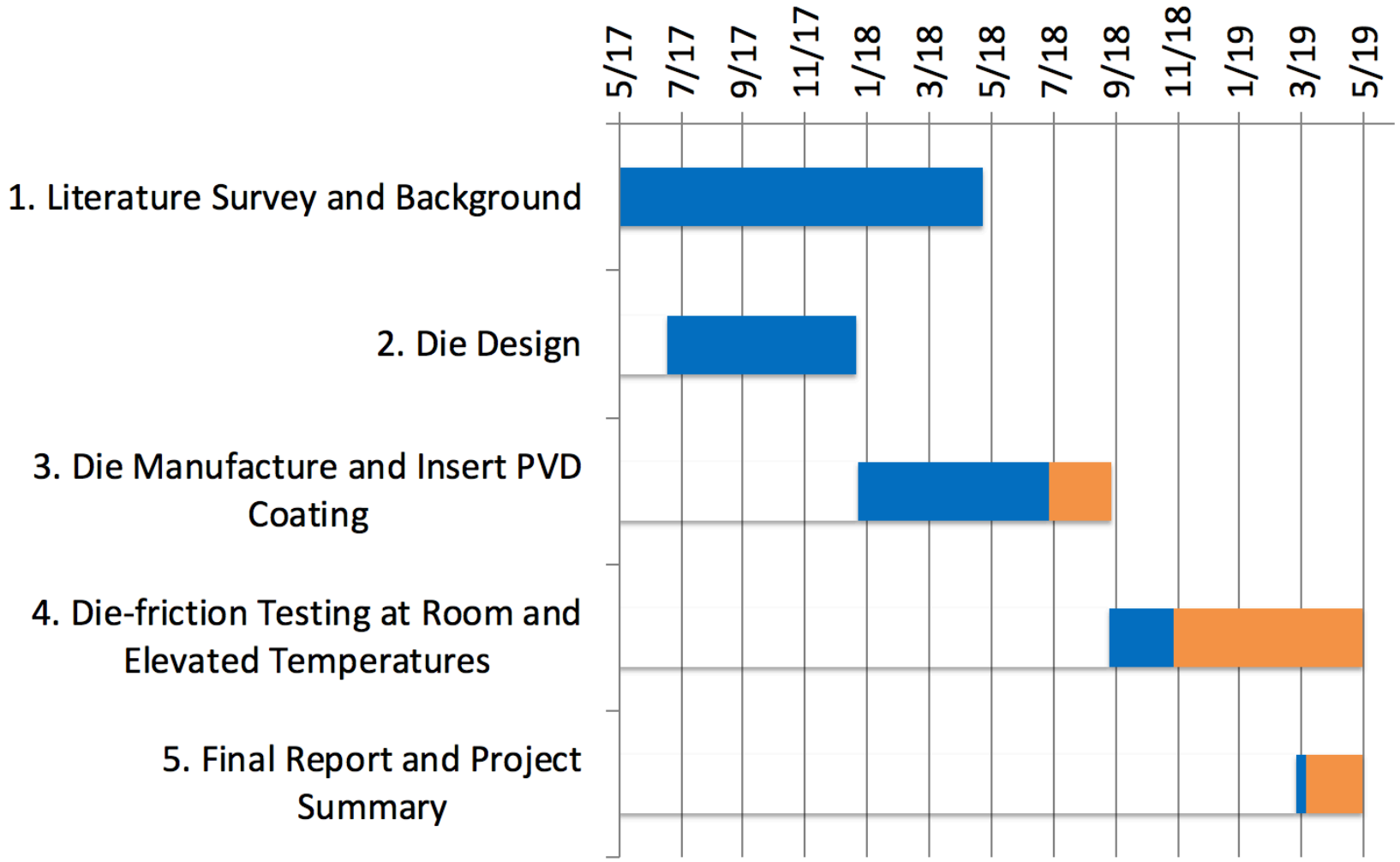
- Flexible forging tooling has been designed and built
  - Room temperature to 500°C
  - Loads to 100 kip
  - 6 sets of interchangeable die inserts
- Ring-compression friction tests have been validated
  - Polished as-heat treated (uncoated) dies
  - Room temperature to 300°C
- Forging die coatings
  - Literature review complete
  - List of promising coatings compiled
  - Four initial PVD coatings selected for application to dies (just received!)

Progress



Trevor Kehe

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- Senior in Metallurgical and Materials Engineering, graduating May 2019.
- Future Plans
  - Graduate school (Master's) in physical metallurgy or corrosion
- Other Interests
  - Hiking, climbing, baseball
- Mines Baseball
  - 2nd in RMAC

Acknowledgements

- FIERF – stage gated grant, “Laboratory Testing to Identify Permanent PVD Coatings to Minimize Lubricants Use During Forging”

- FIERF board – stage gate reviews and guidance

- Die materials
  - Bohler-Uddeholm (Patricia Miller), H13 and W303 inserts
  - Hitachi (Tom Bell), H13 inserts
  - Finkl (Al Underys), 4340 die blocks

- NSF REU program grant through the Center for Advanced Non-Ferrous Structural Alloys

- CSM undergraduate research support

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Thank you very much!

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

Industrial Partners: *QCF, FIERF*

Project Duration: *May 2017 – May 2019*

Achievement

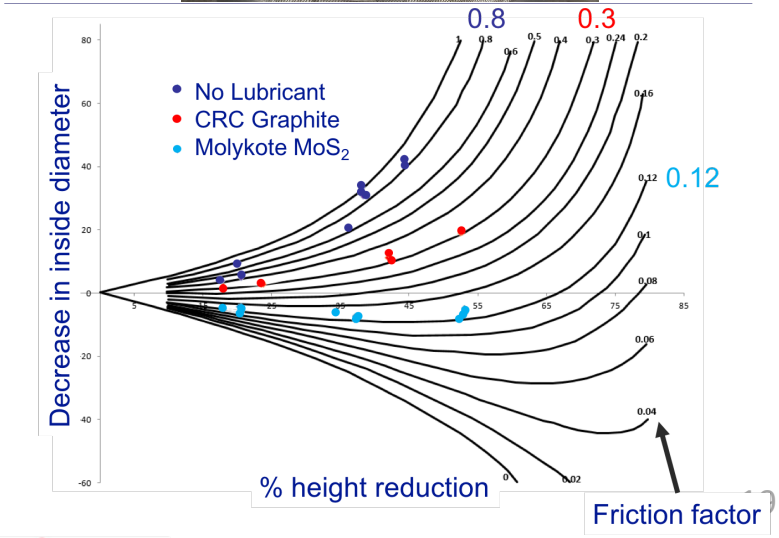
- Developed test methodology to measure friction coefficients during forging at temperatures up to 500°C.

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

- Initial trials on newly designed tooling show easily distinguishable friction coefficients with varying test conditions.



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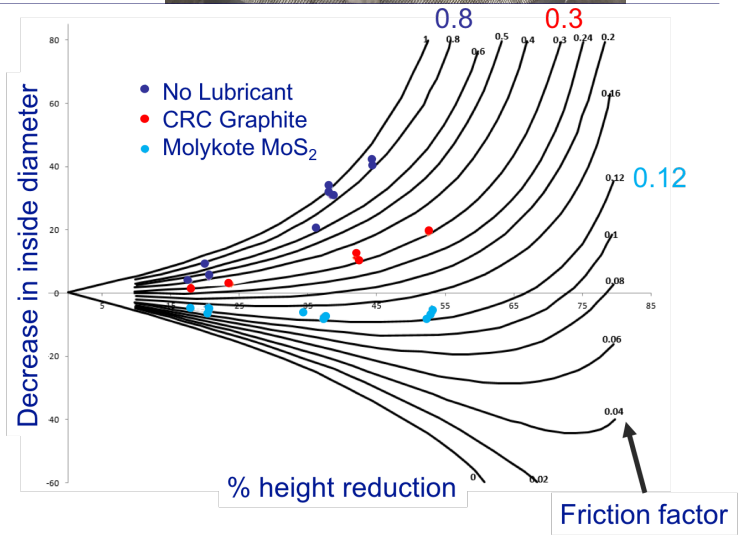

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Program Goal

- 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.