CANFSA

Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Project 37-L: Advanced Engineered Coatings with Extended Die Life for Tooling

Semi-annual Spring Meeting
April 2022

- Student: Nelson Delfino de Campos Neto (Mines)
- Faculty: Andras Korenyi-Both, Stephen Midson, Michael Kaufman (Mines)
- Industrial Mentors: Paul Brancaleon (NADCA), Rob Mayer (Queen City Forging Co.)

COLORADO SCHOOL OF MINES   NSF   IOWA STATE UNIVERSITY

Project 37-L: Advanced Engineered Coatings with Extended Die Life for Tooling

- Student: Nelson Delfino de Campos Neto (Mines)
- Advisor(s): S. Midson, A. Korenyi-Both, M. Kaufman (Mines)

Project Duration

PhD: August 2018 to July 2023

- Problem: Molten aluminum tends to solder to die faces during the die casting process. Lubricants are applied to the die to reduce soldering and adhesion, but the lubricant reduces part quality.
- Objective: Identify PVD coatings to be applied to die casting dies to prevent soldering. Understand the mechanisms involved with adhesion.
- Benefit: Increase die casting part quality, eliminate the use of lubricants, extend die life and reduce cost-per-part.

Recent Progress

- Performed controlled laboratory die casting experiments at The Ohio State University.
- Started industry die casting trial at Stellantis.
- Characterization on tested core pins.
- Published paper: “The Use of Coatings to Minimize Soldering and Eliminate the Need for Lubrication during Aluminum High Pressure Die Casting” at Transactions of the NADCA 2021 Die Casting Congress & Exposition.

Metrics

Description	% Complete	Status
1. Literature review and development of molten aluminum tests	100%	●
2. Identification of the mechanisms that controls soldering and adhesion behavior	100%	●
3. Identification of PVD coatings to avoid molten aluminum soldering and adhesion	90%	●
4. Identification of PVD coatings durability to survive as long as the die casting dies (100,000 shots)	80%	●
5. In-plant trials. Guidelines for depositing the coating system on die components/tooling	35%	●

Industrial Relevance

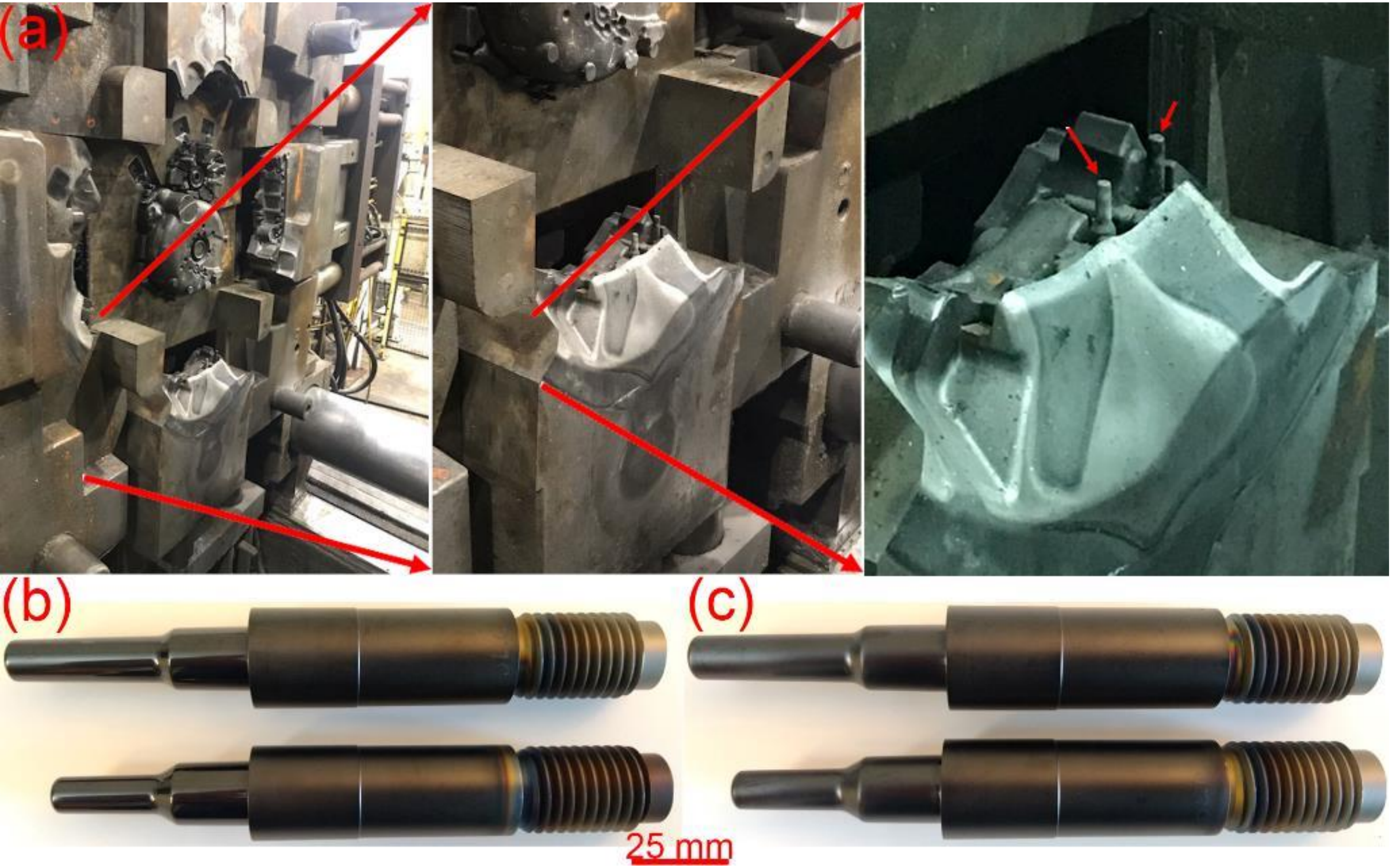
- Reducing or eliminating lubricant spray will:
  - Significantly **improve the quality** of the die castings
    - Reduce gas porosity and scrap
    - Allow castings to be used in higher performance applications
  - **Reduce costs**
    - Eliminate purchase costs for lubricants
    - Reduce effluent clean-up costs
    - Significantly extend die life
  - **Improve productivity**
    - Faster cycle rates

Aluminum HPDC Tests

- Two sets of tests to find best PVD coatings for lube-free die casting
- Planned testing at The Ohio State University (OSU)
  - 250 ton Buhler die casting machine
  - Controlled laboratory test
  - Try to run lube-free
- Planned testing at Stellantis (Kokomo Die Casting Plant)
  - 3,000 ton commercial die casting machine
  - Run PVD coated core pins for 2,500 shots
    - Evaluate soldering of different PVD coatings
  - Evaluate soldering progression and coating life

Testing at Stellantis
(Kokomo Die Casting Plant)

Core Pin Soldering at Stellantis



- Runs single cavity on a 3,000-ton die casting machine
- The two very similar core pins are shown on the bottom
  - Utilize internal water cooling
- Core pins with two surface finishes were PVD coated
  - Rougher draw-polish finish
  - Smoother diamond polish
- Around 2,500 aluminum die castings will be made to track steady-state soldering

3D Optical Images

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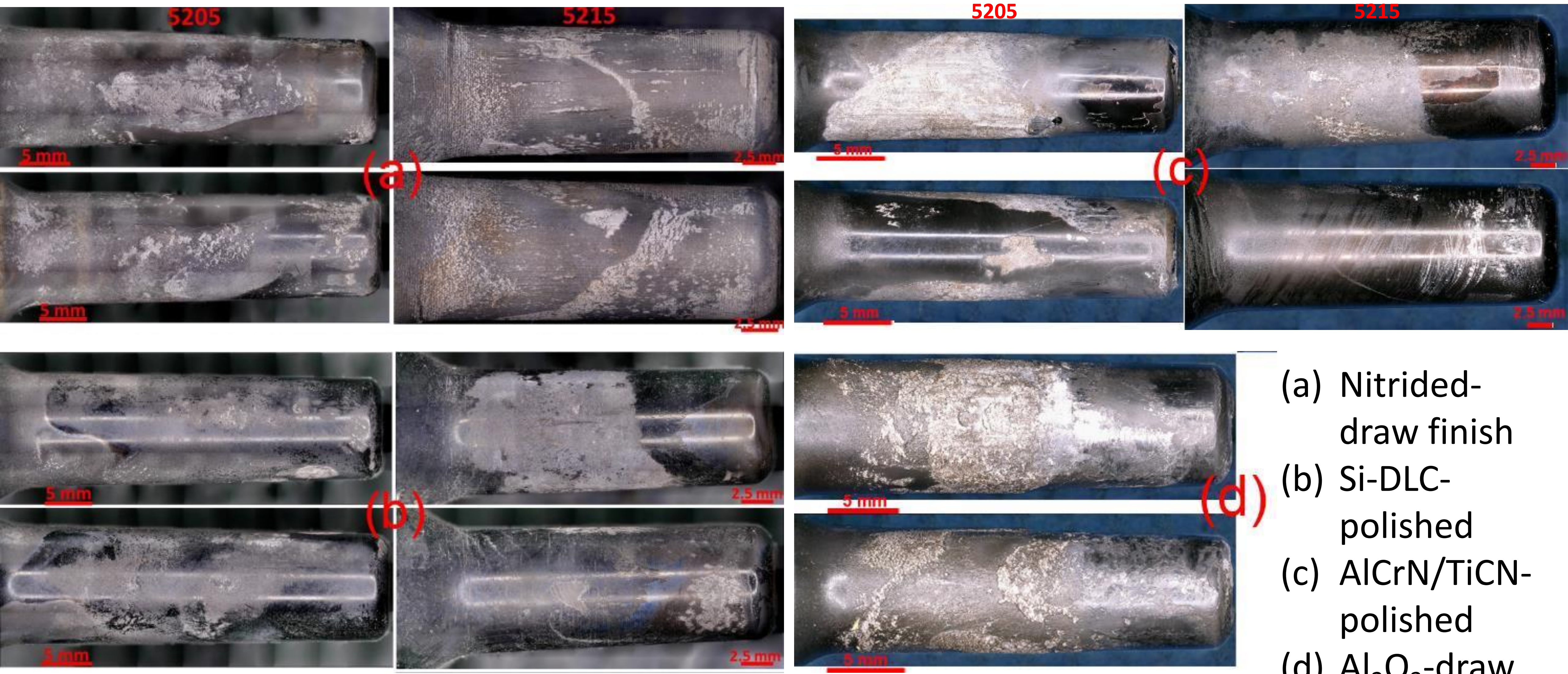
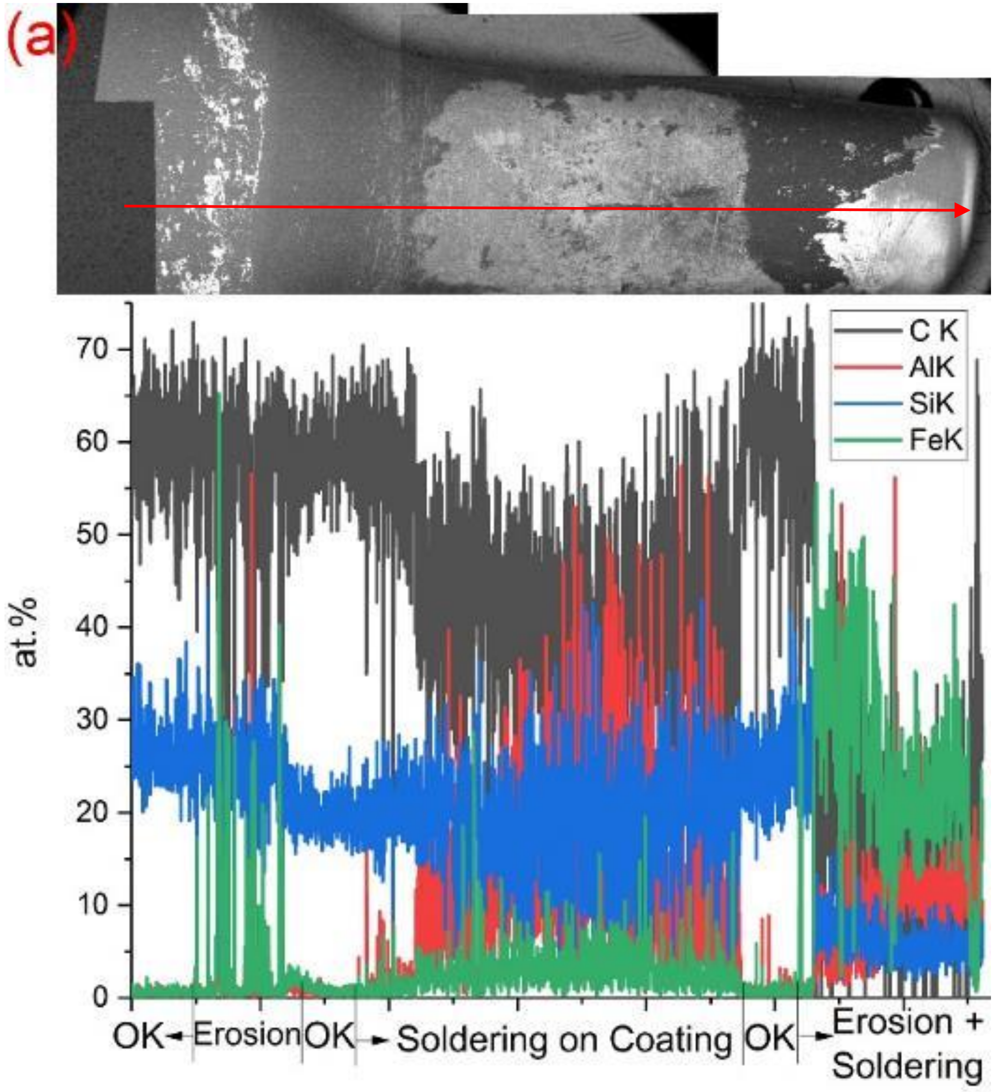
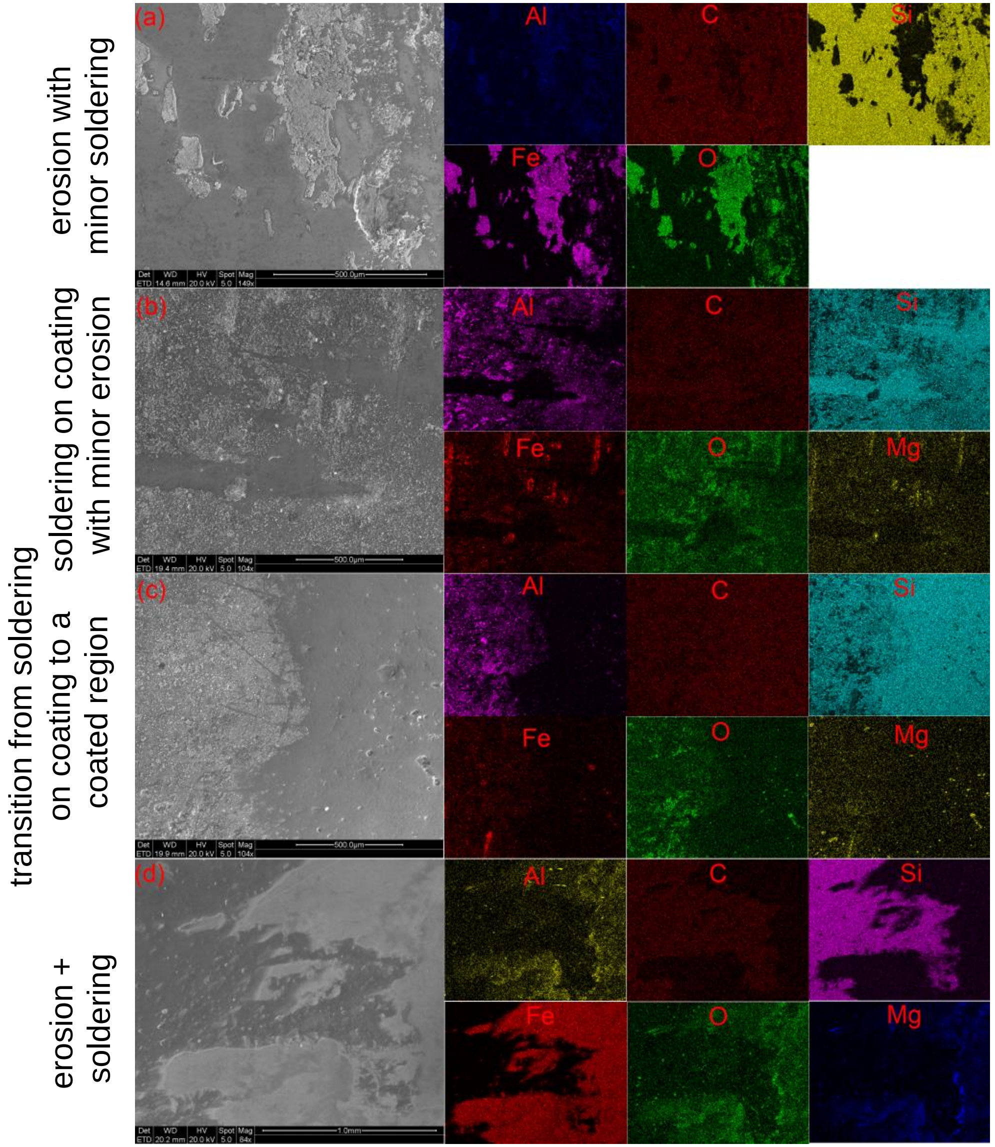


(a) Nitrided-draw finish
(b) Si-DLC-polished
(c) AlCrN/TiCN-polished
(d) Al_2O_3-draw

Si-DLC-polished 5215 Soldering Mechanisms

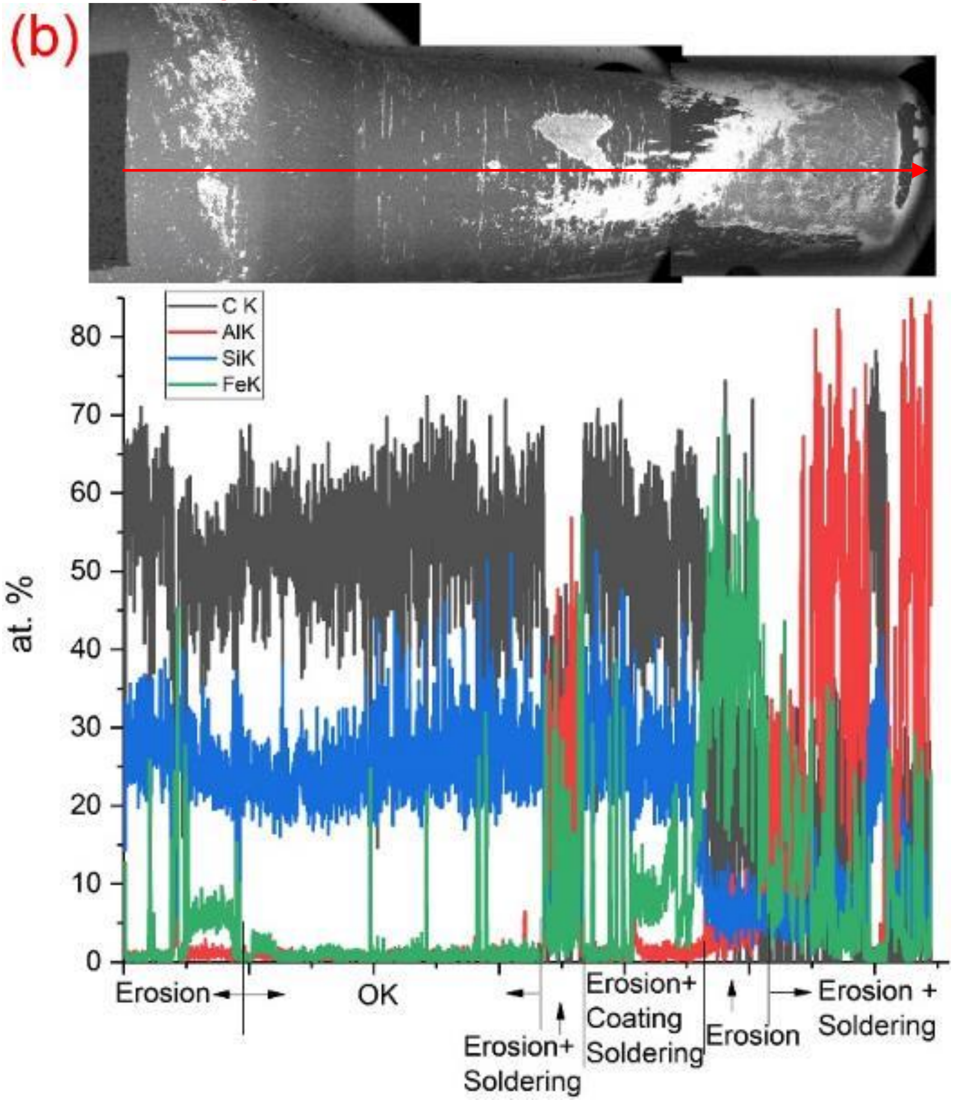
Facing Gate

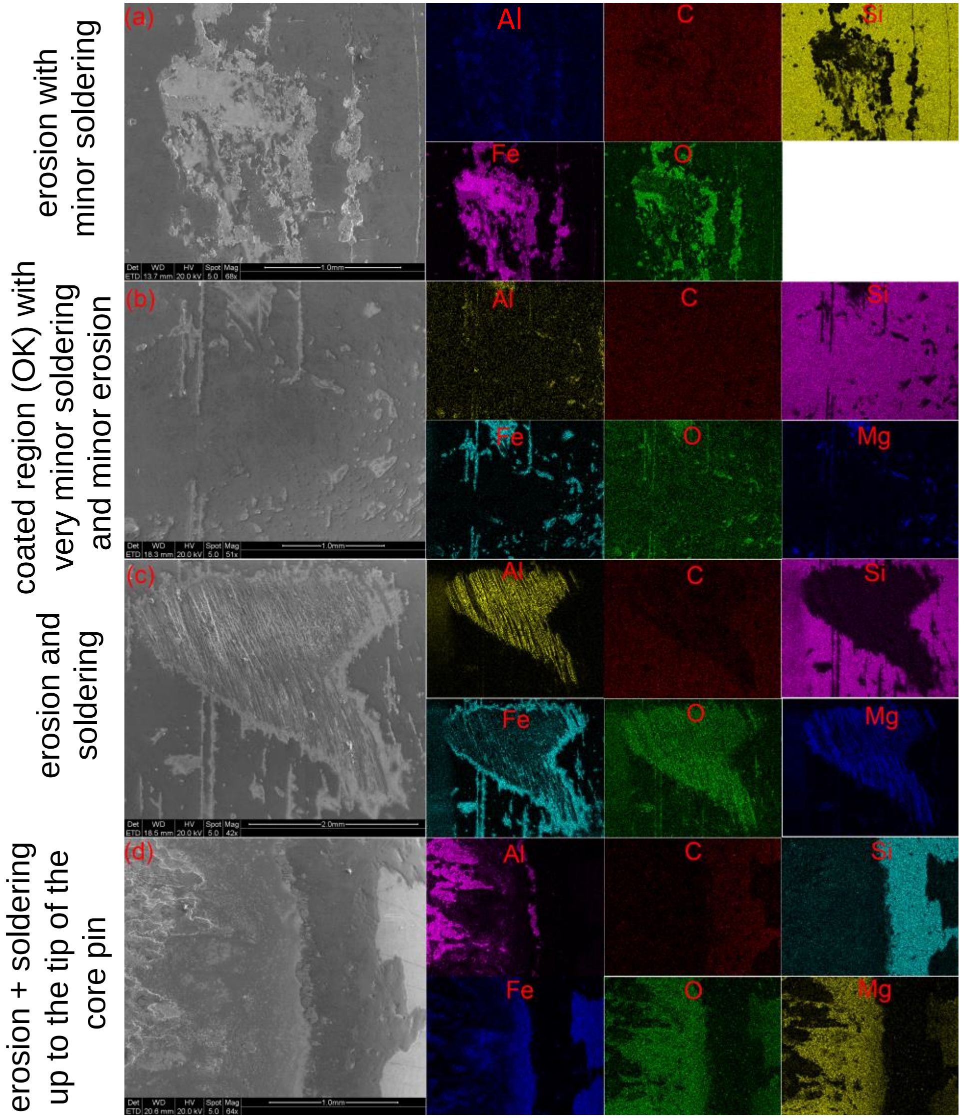




Si-DLC-polished 5215 Soldering Mechanisms

Opposite Side of Gate

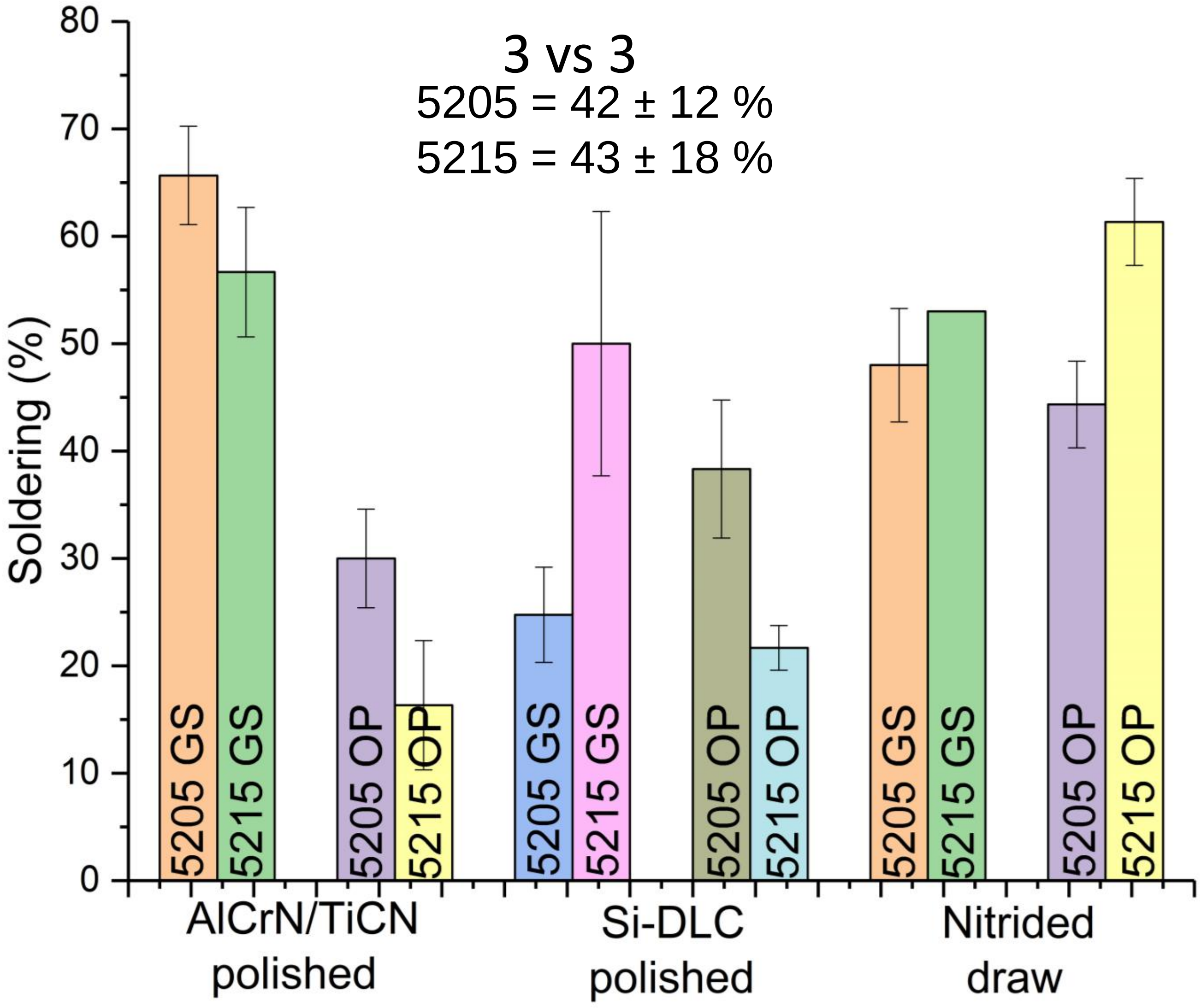


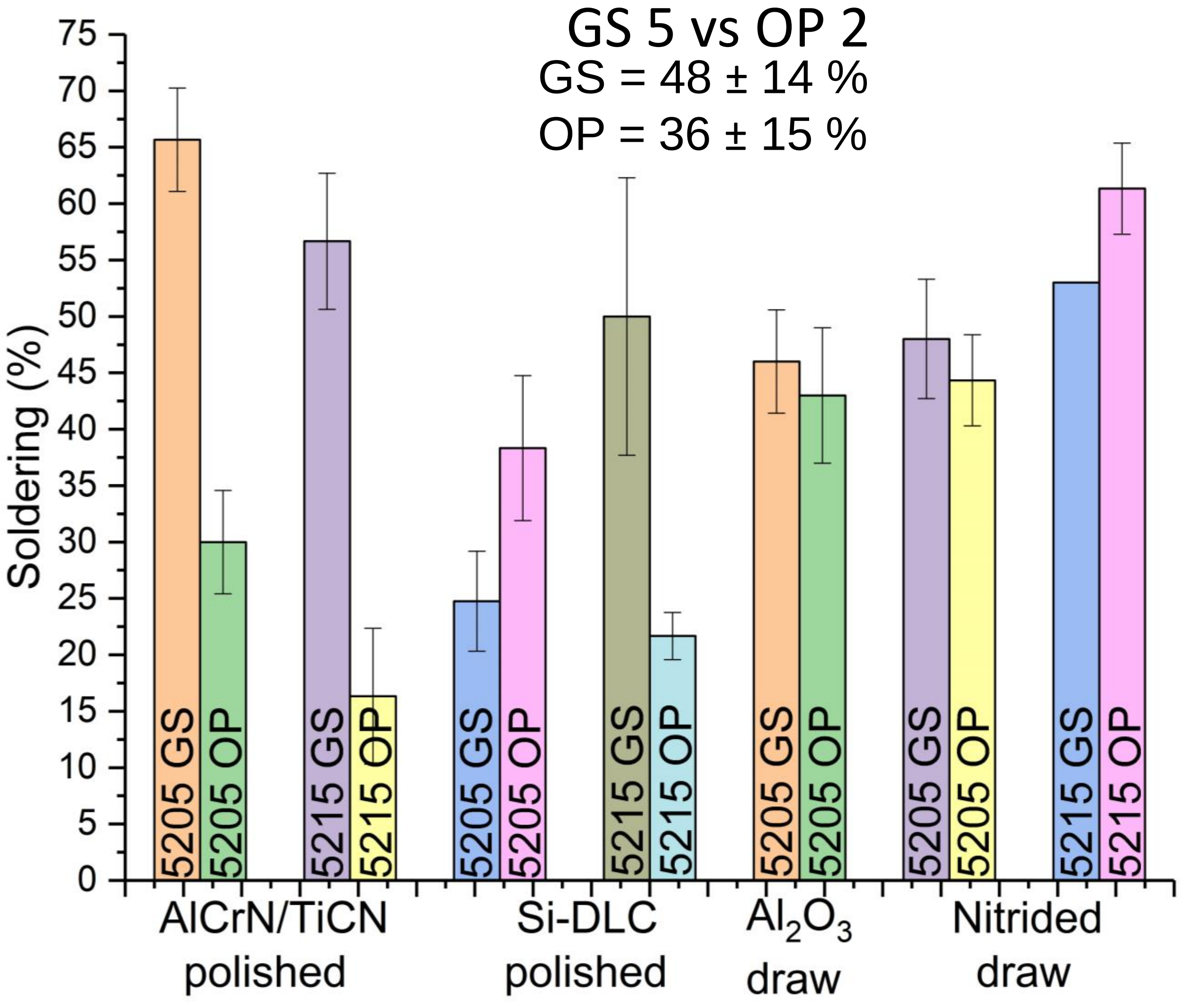


Qualitative Grade and Quantitative Results

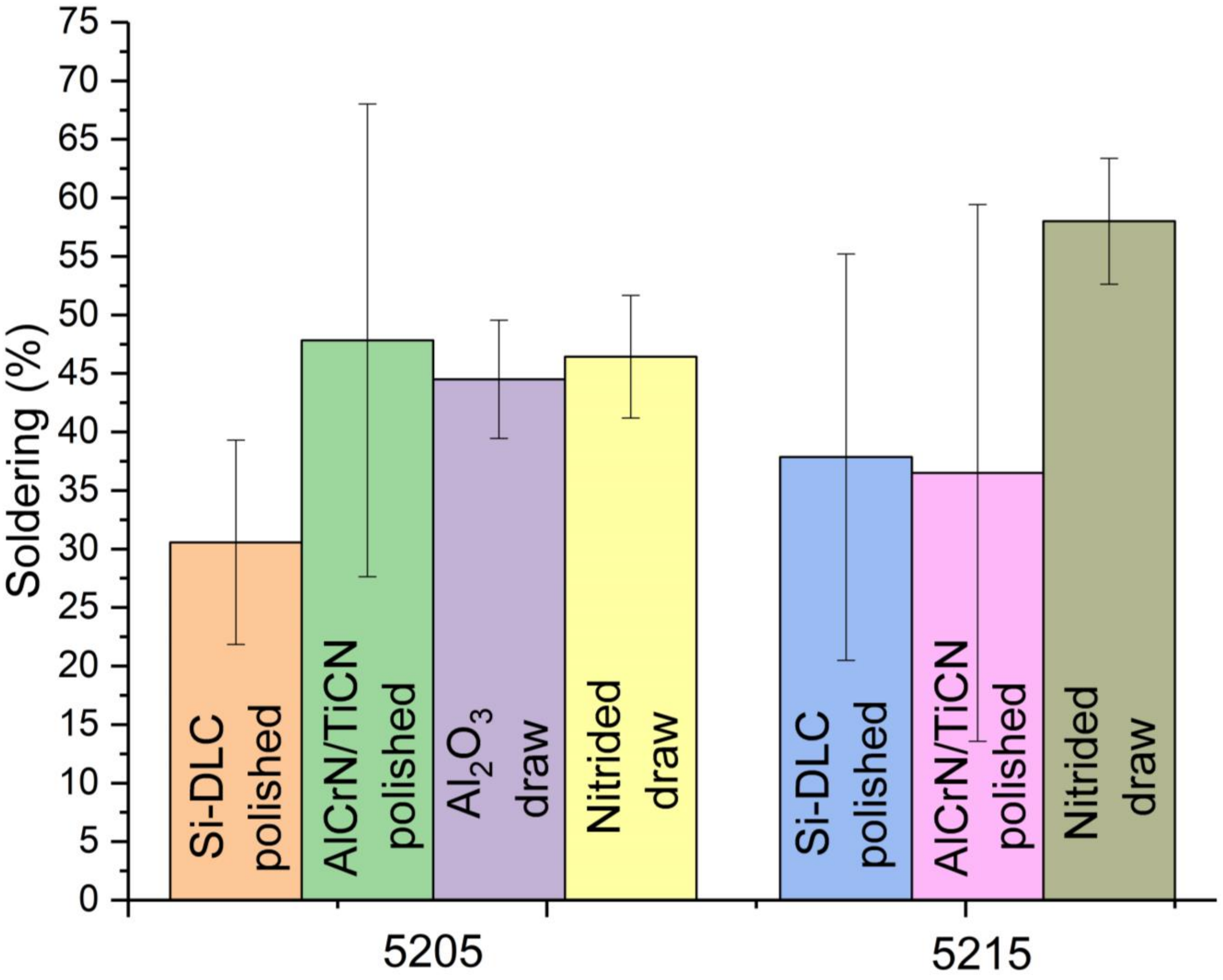
Coating	Coating Supplier	# of Shots	Stellantis Observations	Stellantis Grade	Mass change (5205)	Mass change (5215)	Surface Soldered (5205)	Surface Soldered (5215)
Nitrided (draw)	-	2500	Both cores soldered	D	N/A	N/A	46 ± 5 %	58 ± 5 %
Si-DLC (polished)	#1	2430	Cores basically clean - no solder. Coating looks like it is intermittent.	A-	+ 0.20 g	+ 0.28 g	31 ± 9 %	38 ± 17 %
Si-DLC (draw)	#1	2503	Cores look clean. Note: core puller could have rubbed off some soldering.	B+	-	-	-	-
VC (polished)	#1	4469	Some light solder (cores destroyed)	B-	N/A	N/A	N/A	N/A
Al_2O_3 (polished)	#1	2572	Some solder (cores destroyed)	C+	N/A	N/A	N/A	N/A
Al_2O_3 Alumina (draw)	#1	3818	One core fairly clean and one had solder. Soldering on gate side.	C-	+ 0.17 g	N/A	45 ± 5 %	N/A
AlCrCN (polished)	#5	4112	One core relatively clean and one with solder. Soldering happening on gate side.	D+	+ 0.19 g	- 0.17 g	48 ± 20%	37 ± 23 %

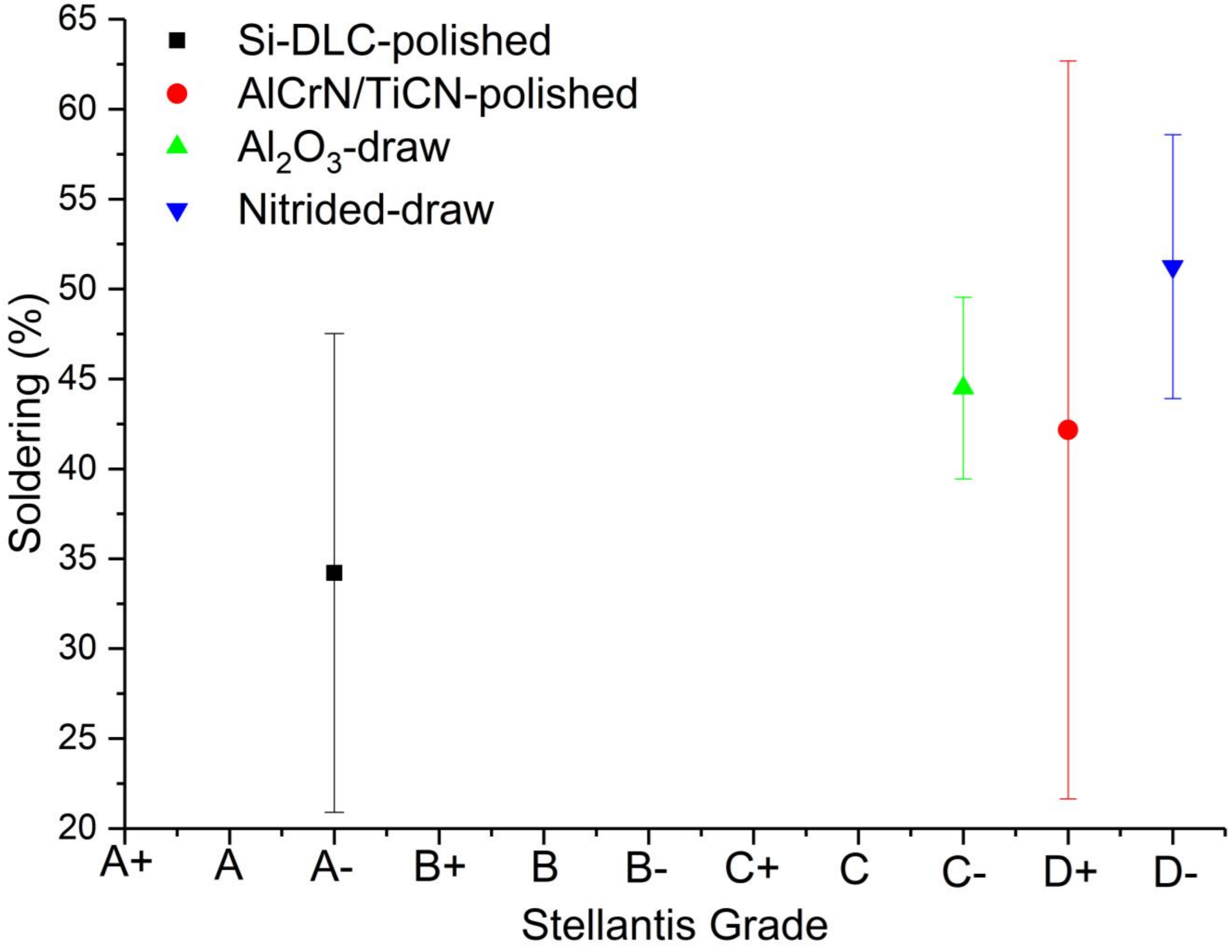
Soldering on Core Pins 5205 vs. 5215 and GS vs. OP



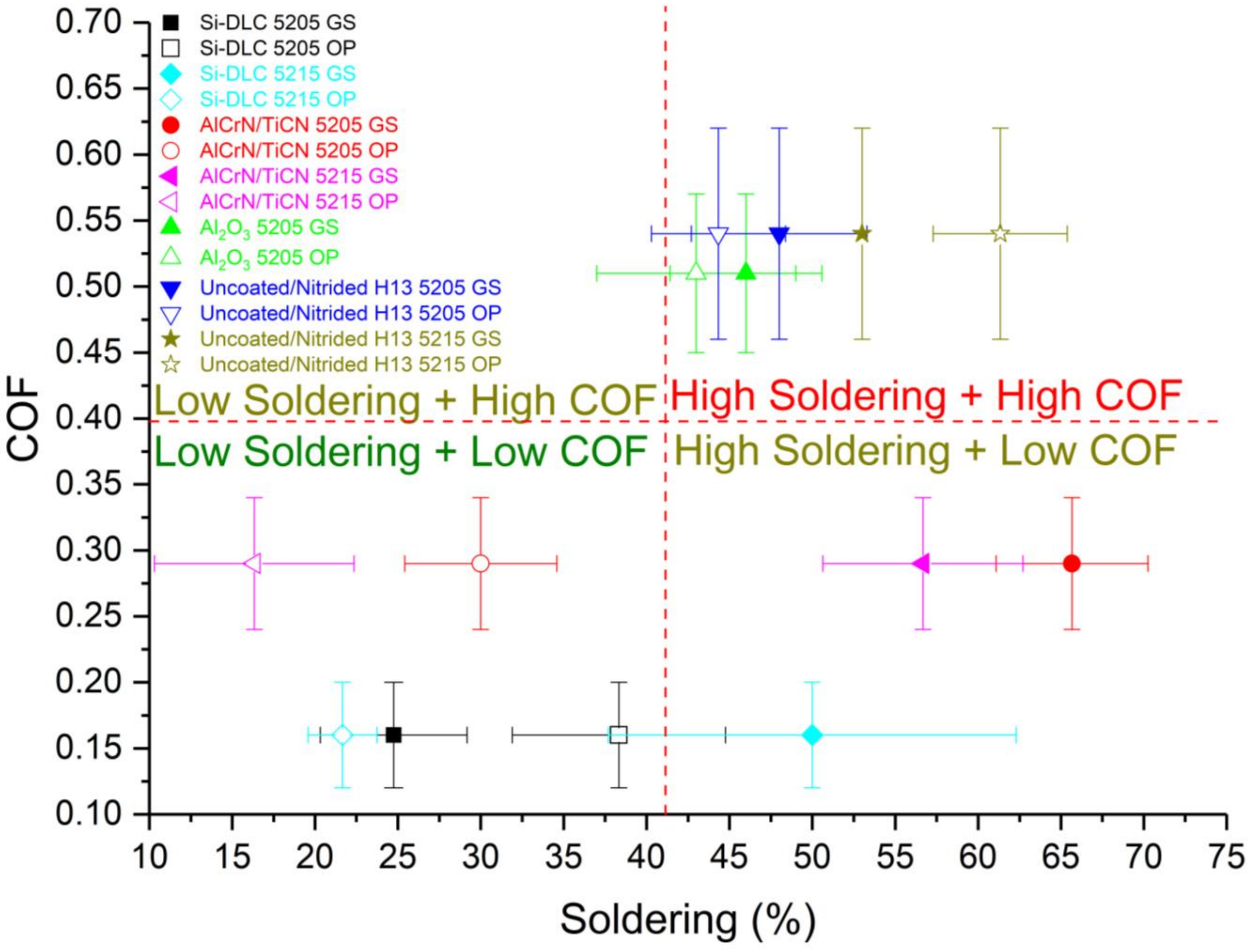


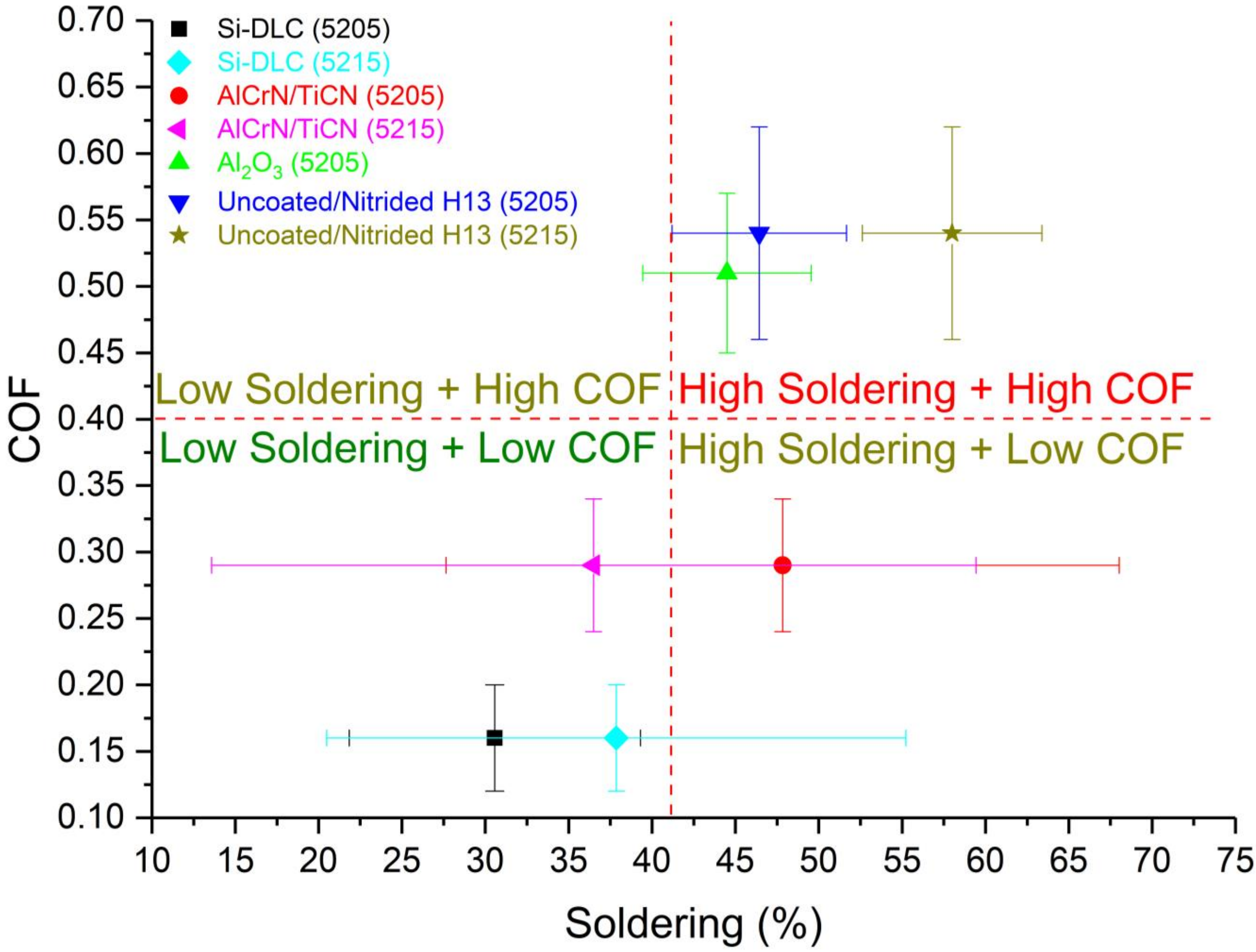
Soldering by Coating and Stellantis Grade



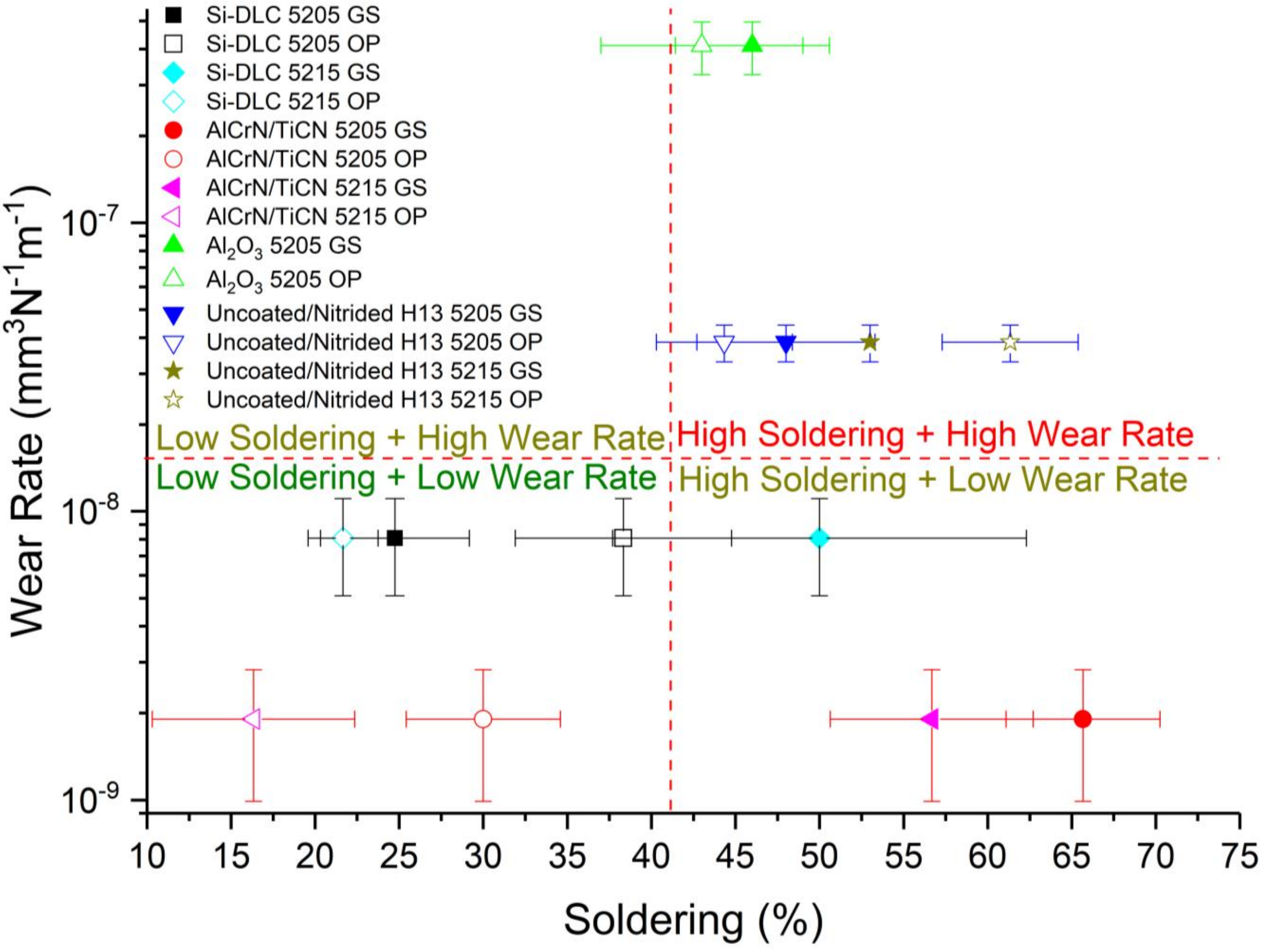


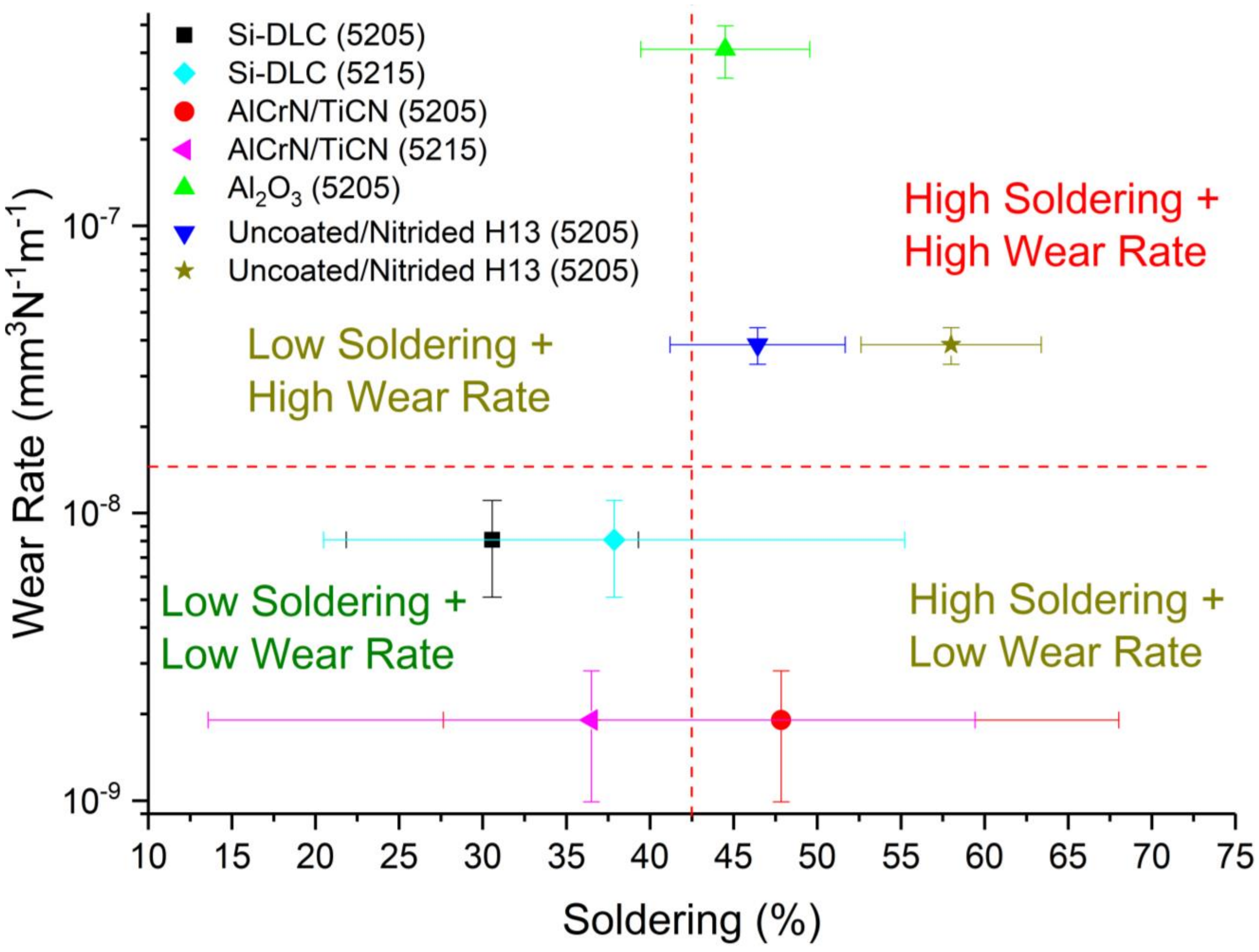
Tribology Parameter COF and Soldering



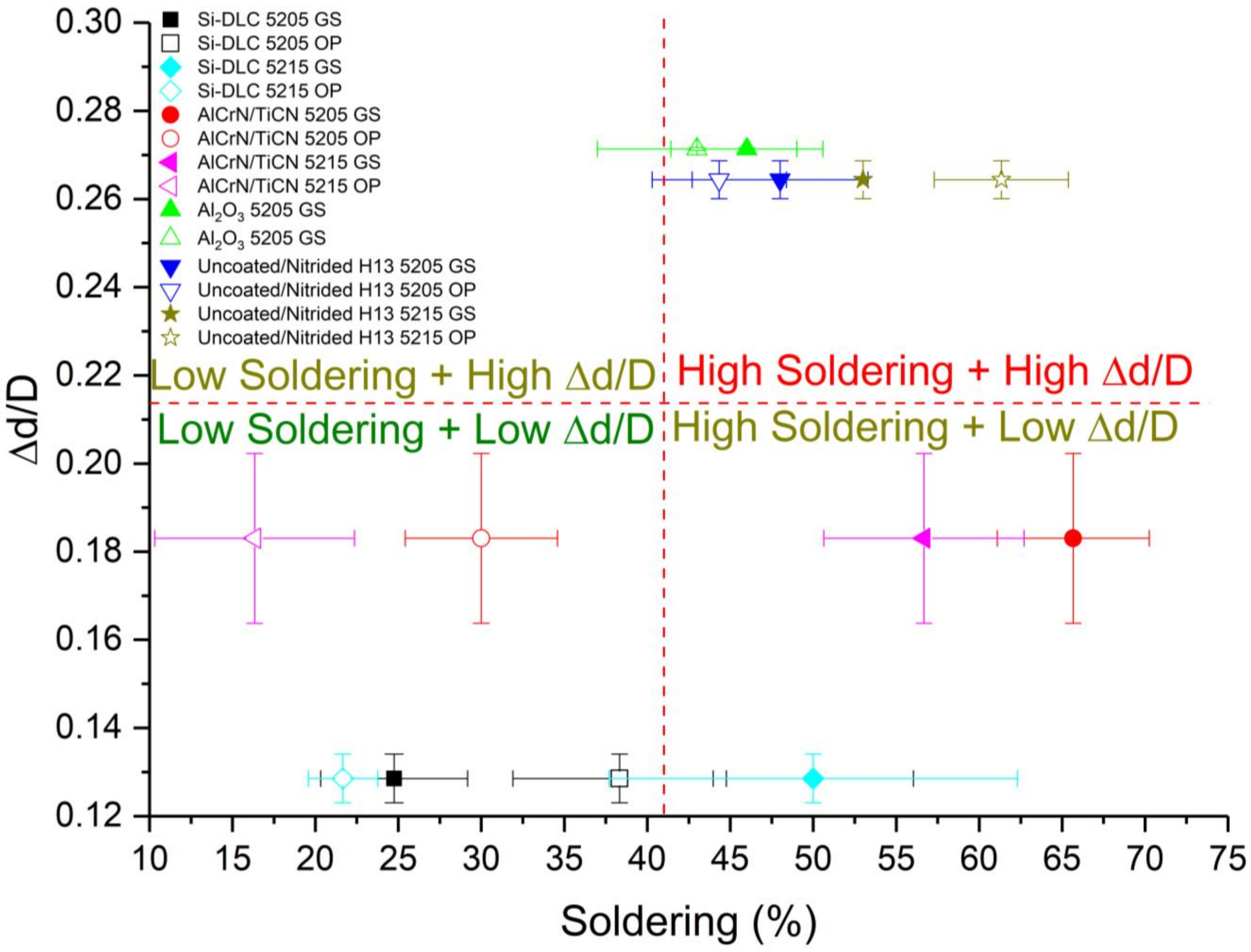


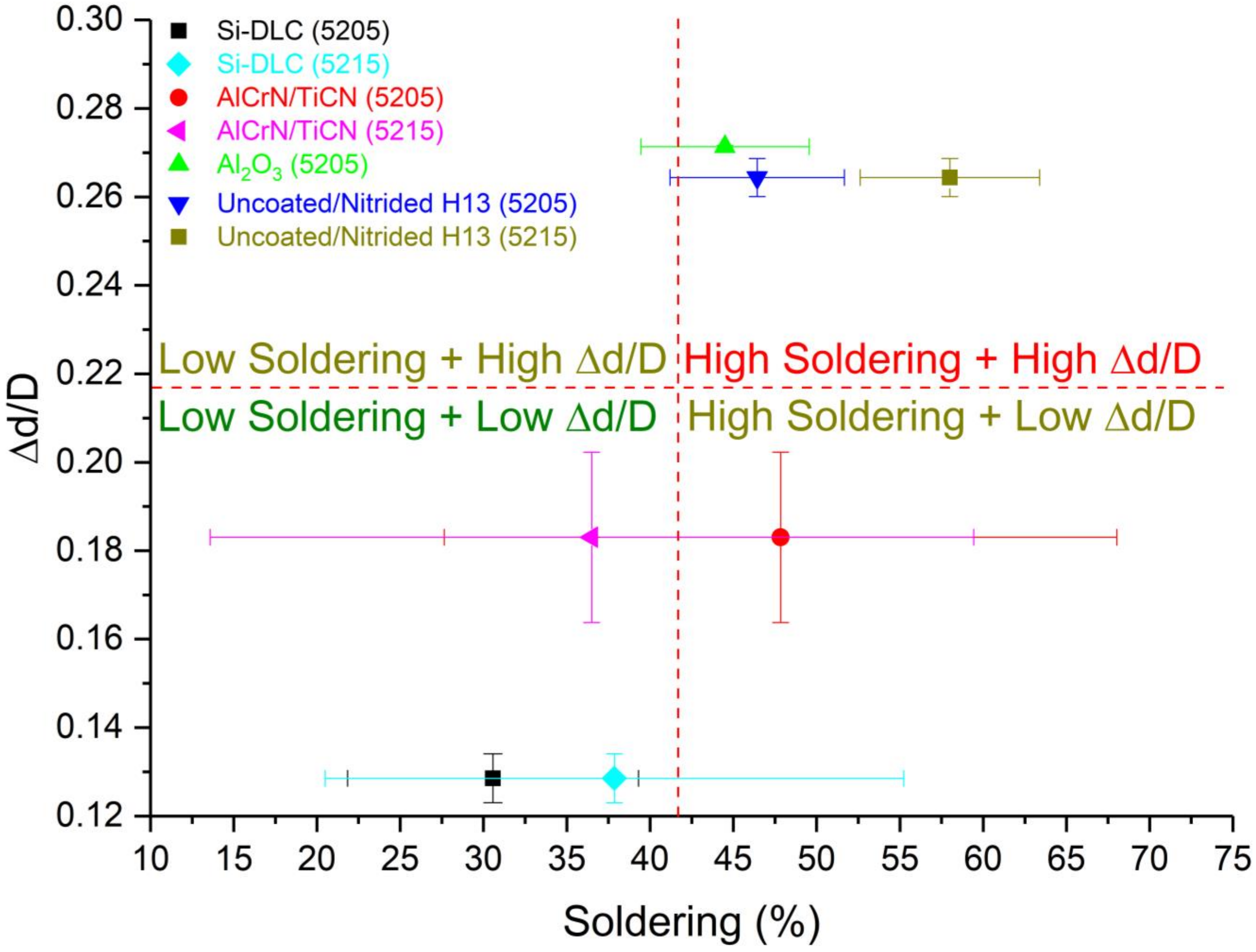
Tribology Parameter Wear Rate and Soldering



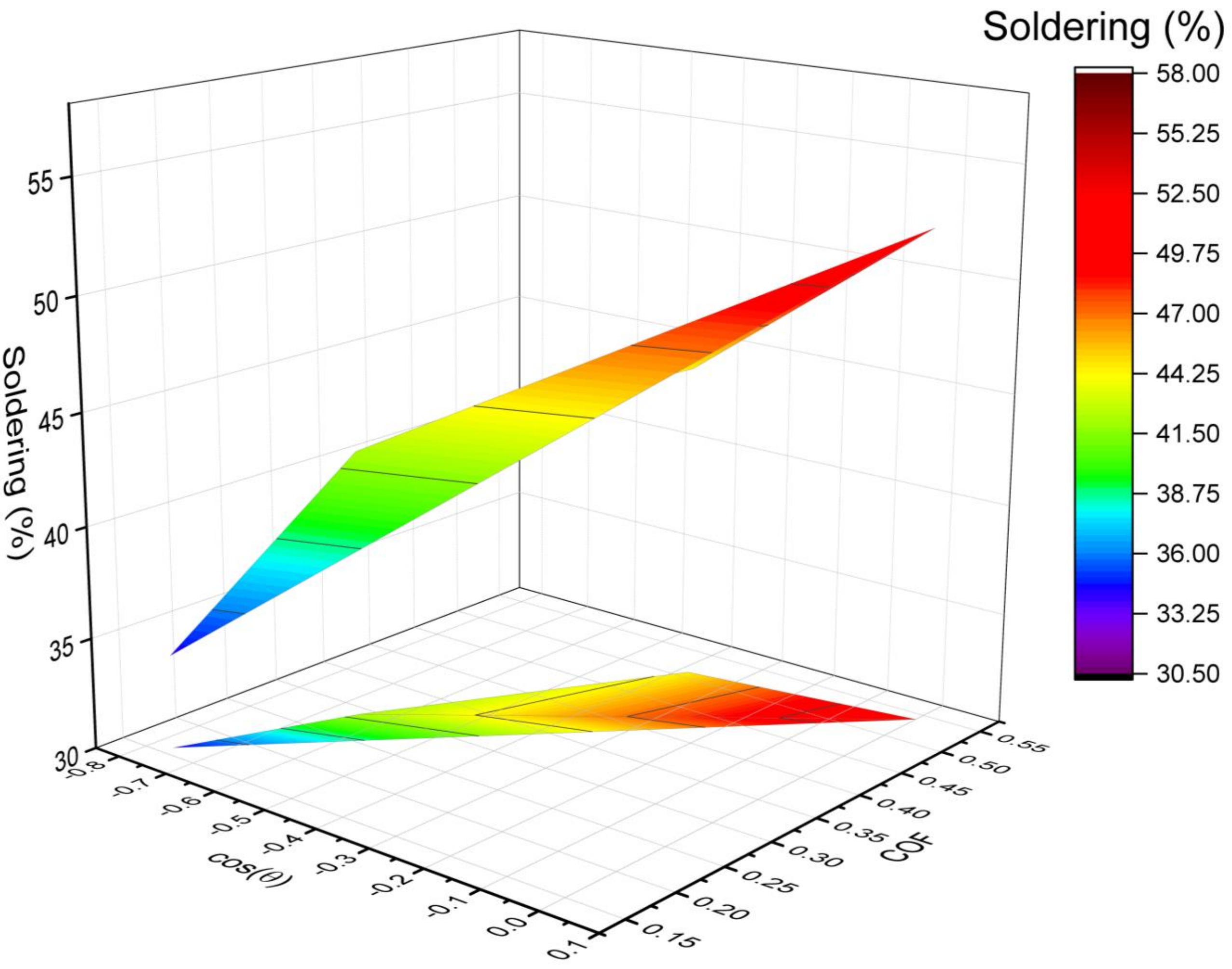


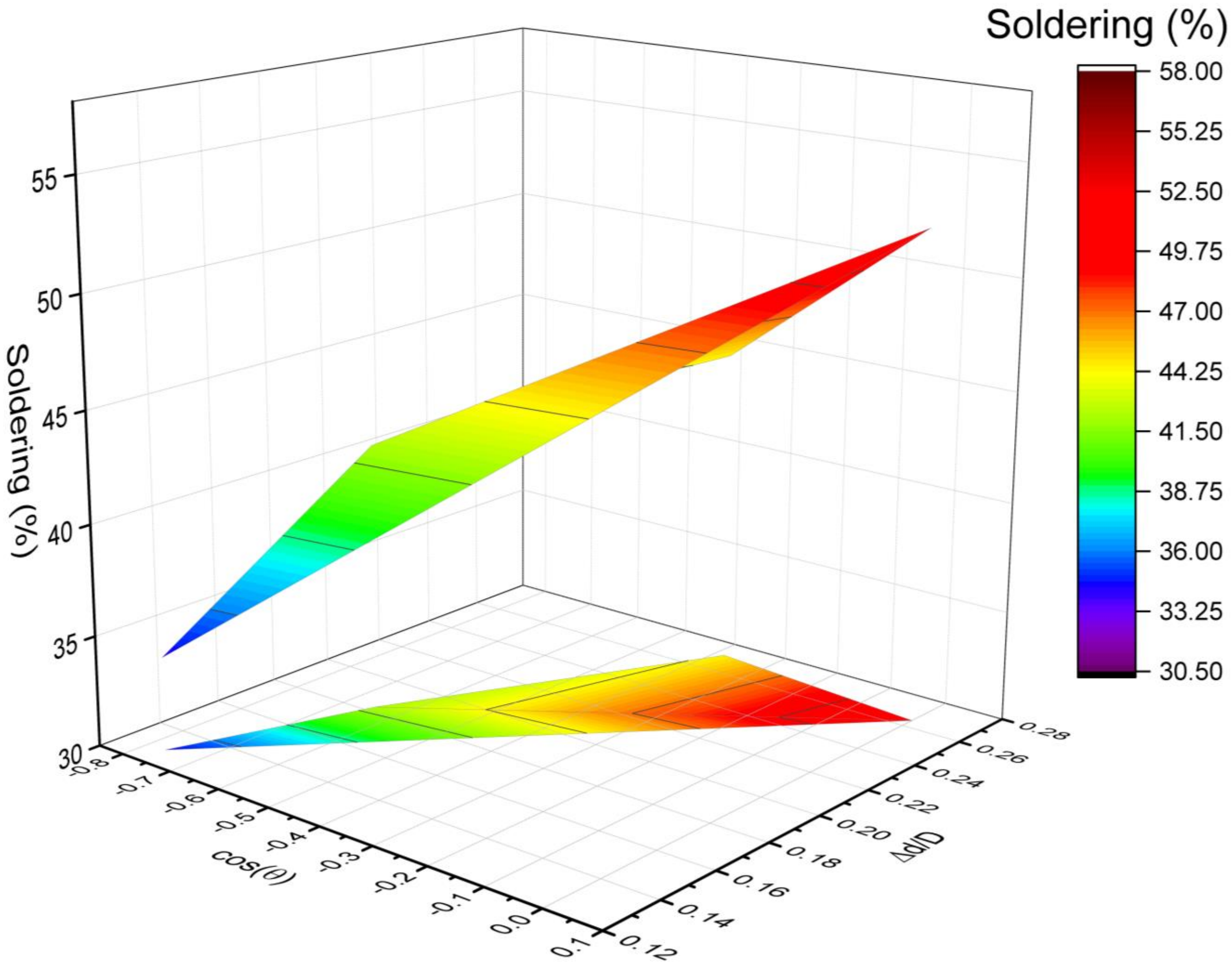
Tribology Parameter Δd/D and Soldering



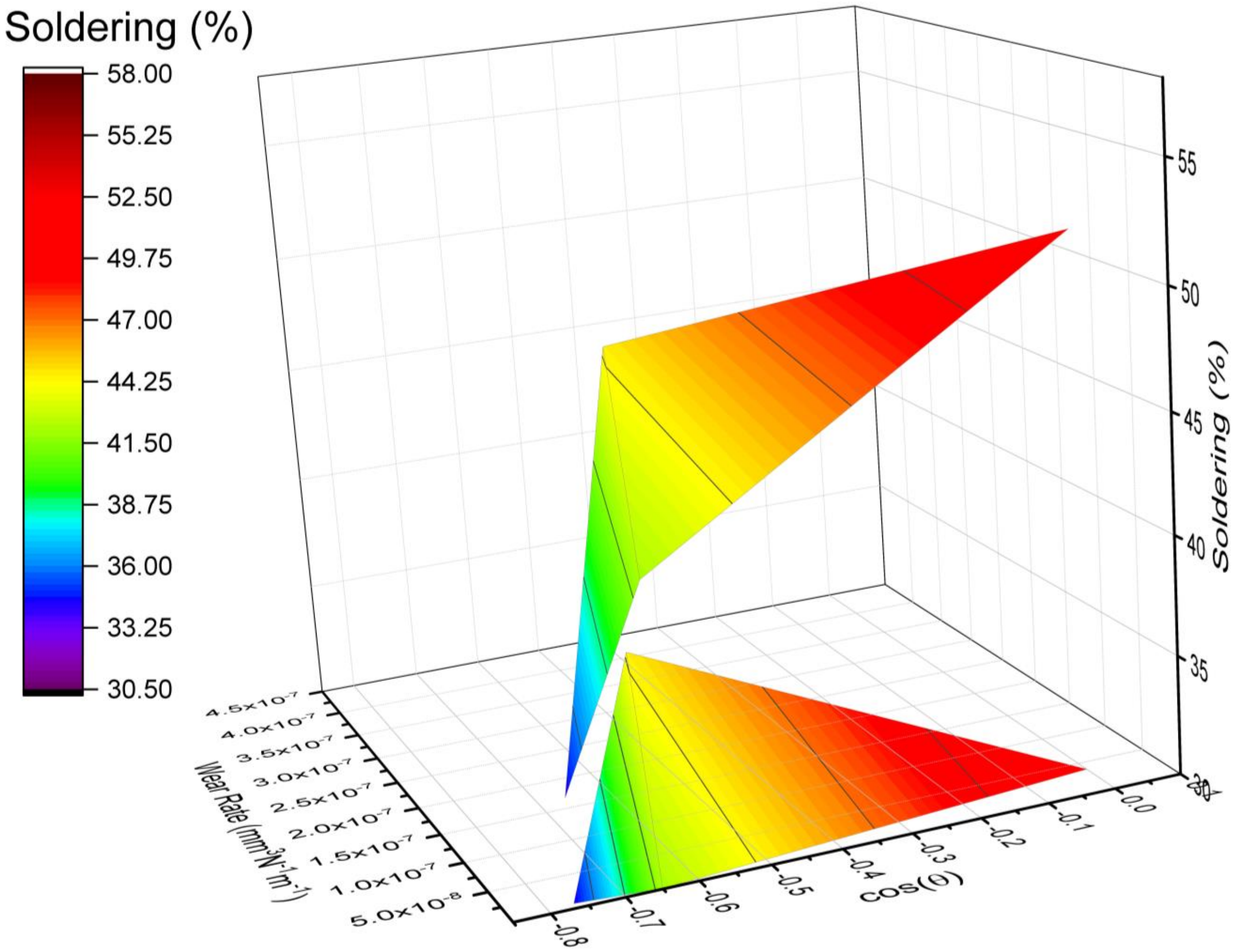


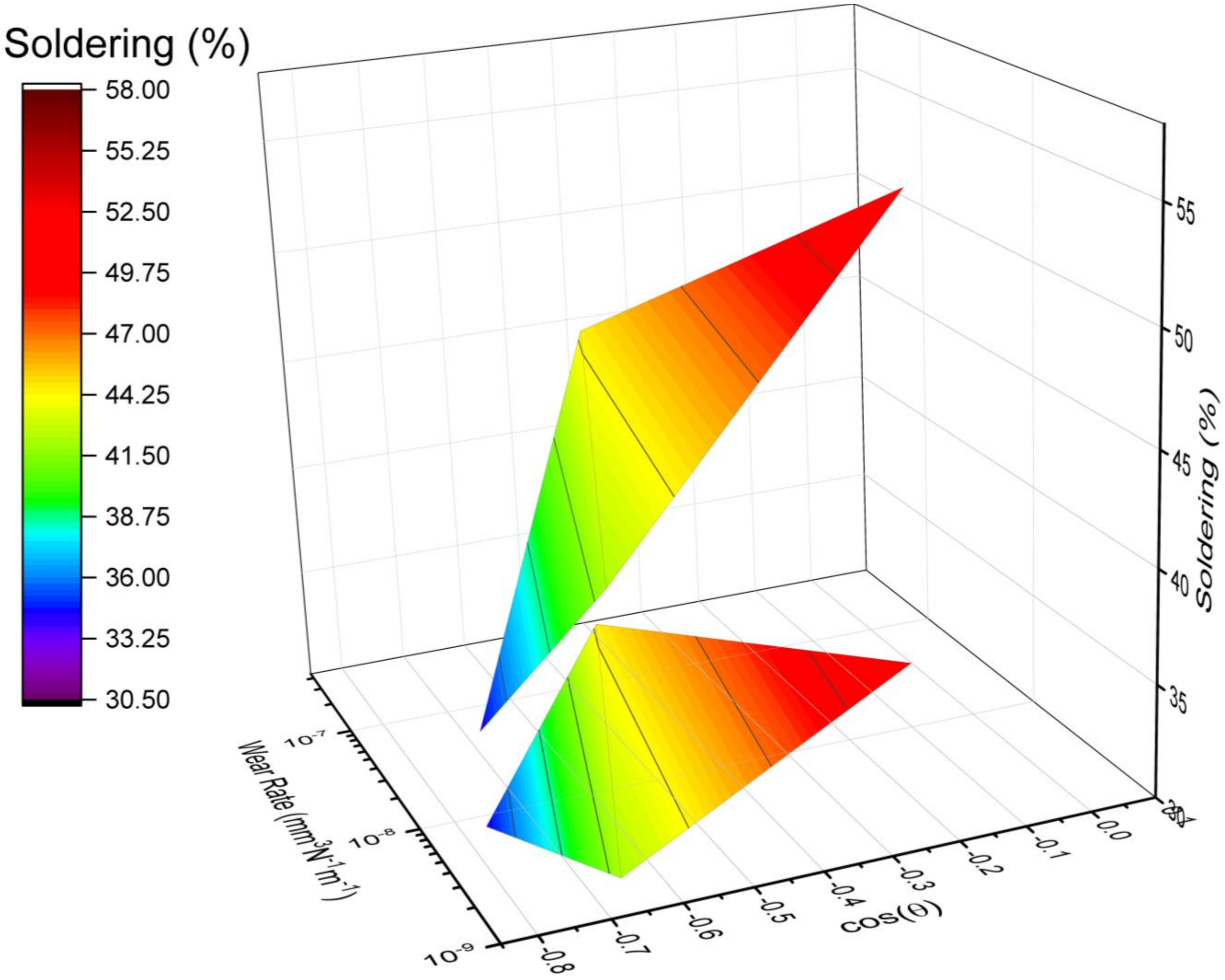
Wetting and Tribology Trends on Soldering





Wetting and Tribology Trends on Soldering





Center Proprietary – Terms of CANFSA Membership Agreement Apply

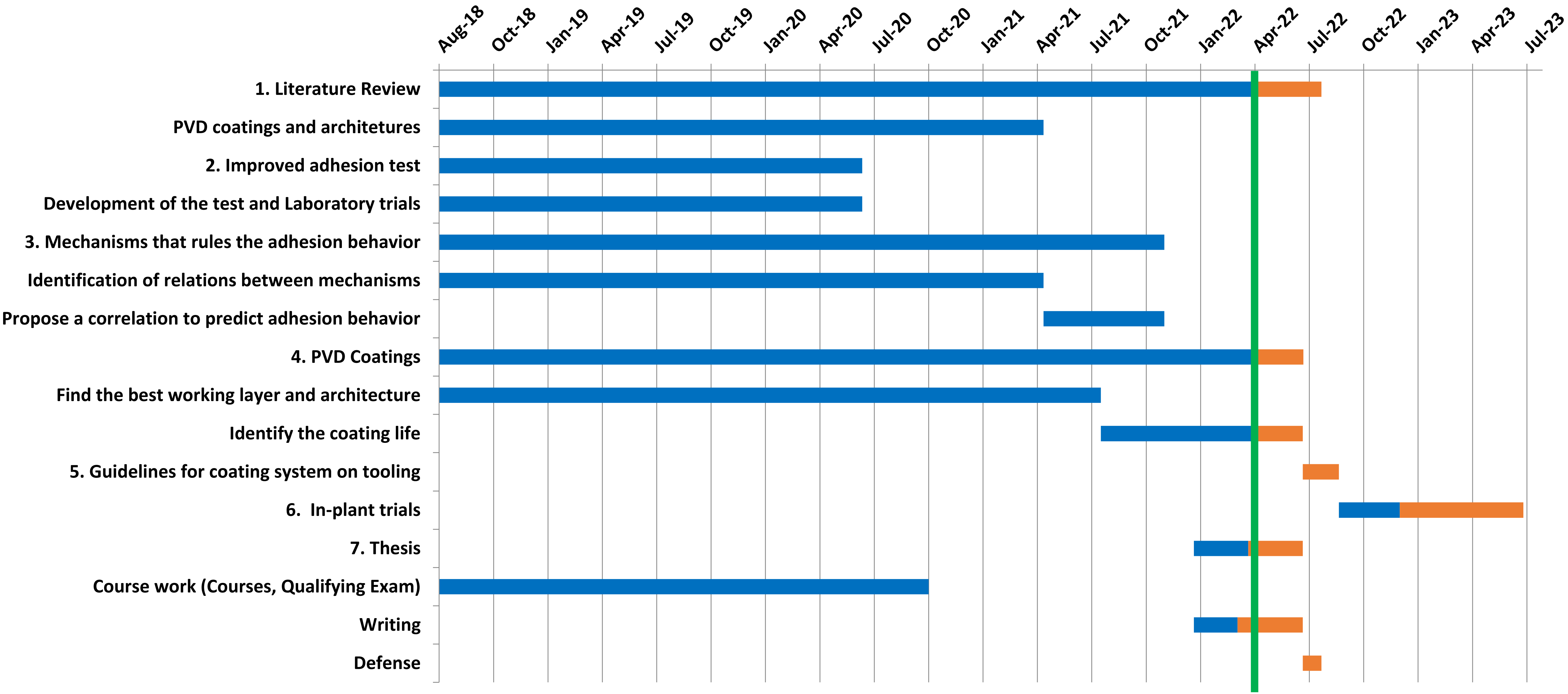
Summary & Conclusions

- Casting trials at Stellantis for coated core pins positioned directly in-front of the gate
  - Seven sets of core pins have been tested so far
  - Similar soldering mechanisms were found on the core pins differing on its extent and position
    - Erosion, soldering, gross soldering, soldering on coating, and erosion/thermal spalling were the main mechanisms
  - Similar amount of soldering was found for both core pins 5205 and 5215
  - The side of the core pins facing the gate suffered more soldering than the opposite side
  - Coated core pins presented less soldering than the only Nitrided condition
  - Si-doped DLC coating exhibited the least amount of soldering
  - Exclusion maps were developed combining the tribology parameters COF, wear rate and $\Delta d/D$ and the measured soldering
  - Trends were observed when combining wetting angles and tribology parameters COF and $\Delta d/D$ with the measured soldering
    - Similar trend was not found for the tribology parameter wear rate

Future Work

- Continue coated core pins soldering trial at Stellantis
- Characterization of PVD coatings
  - Adhesion quality
  - Structure and microstructure
  - Roughness and surface defects
  - Wear and oxidation resistance
- Characterization of aluminum soldered samples
  - Examine the phases formed at the interface between the solidified aluminum and the tested coatings
- Characterization of the adhesion mechanisms related to soldering
- Transition the best coatings to die casters

Gantt Chart



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1. Literature Review
PVD coatings and architetures
2. Improved adhesion test
Development of the test and Laboratory trials
3. Mechanisms that rules the adhesion behavior
Identification of relations between mechanisms
Propose a correlation to predict adhesion behavior
4. PVD Coatings
Find the best working layer and architecture
Identify the coating life
5. Guidelines for coating system on tooling
6. In-plant trials
7. Thesis
Course work (Courses, Qualifying Exam)
Writing
Defense

Acknowledgements

- This program is sponsored by the Defense Logistics Agency – Troop Support, Philadelphia, PA and the Defense Logistics Agency Information Operations, J68, Research & Development, Ft. Belvoir, VA
- N.D. Campos Neto is thankful to CAPES Brazil for a scholarship from the program DOC-PLENO - Full Doctorate Abroad - Call No. 48/2017 - Selection 2018 process number 88881.175453/2018-01
- Accu-Die & Mold in Stevensville, MI fabricated the die at no cost to the project
- Kind and Co in Wiehl, Germany supplied the steel for the die at no cost to the project
- Century Sun Metal Treating in Traverse City, MI heat treated the steel for the die at no cost to the project
- Phygen Coatings in Minneapolis, MN for PVD coating the die cavities
- IBC Coatings in Lebanon, IN for polishing the core pins
- Tribologix in Golden, CO for allowing the use of coatings testing equipment at no cost to the project
- Stellantis in Kokomo, IN for helping the project
- Dr. Alan Luo and his group at OSU for receiving Nelson as a visiting researcher
- Dr. Ryan Brune at CDME (OSU) for helping in the die casting trials

Challenges & Opportunities

- Run controlled laboratory die casting experiments
  - At The Ohio State University
  - Laboratory size die casting machine (Buhler 250-ton)
  - Machine broke before finishing all proposed experiments
- Run industrial trials on selected coatings deposited on core pins in front of gate to understand steady-state soldering
  - Automotive die casting plant at Stellantis (Kokomo die casting plant)
  - High production volume
  - Difficult to control the trial in a production environment

Thank you!

Nelson Delfino de Campos Neto

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Project 53: Ti-6Al-4V Implant coatings/surface treatments for improved wear performance against UHMWPE

Semi-annual Spring Meeting

April 2022

- Student: Nelson Delfino de Campos Neto, Arrianna Matthews (Mines)
- Faculty: Dr. Michael Kaufman, Dr. Kester Clarke (Mines)
- Industrial Mentors: Scott Bingham, Oscar Quintana (DePuy Synthes)

Project 37: Ti-6Al-4V Implant coatings/surface treatments for improved wear performance against UHMWPE

- Student: Nelson Delfino de Campos Neto, Arrianna Matthews (Mines)
- Advisor(s): Michael Kaufman, Kester Clarke (Mines)

Project Duration
PhD: January 2021 to May 2023

- Problem: Ti-6Al-4V wearing against UHMWPE is the dominant material selection for some knee and other replacement joints.
- Objective: Reducing in service wear rates offers potential for maintaining desired mechanical performance for longer service conditions.
- Benefit: Extending service life reduces the complications associated with total replacement and/or maintenance surgeries.

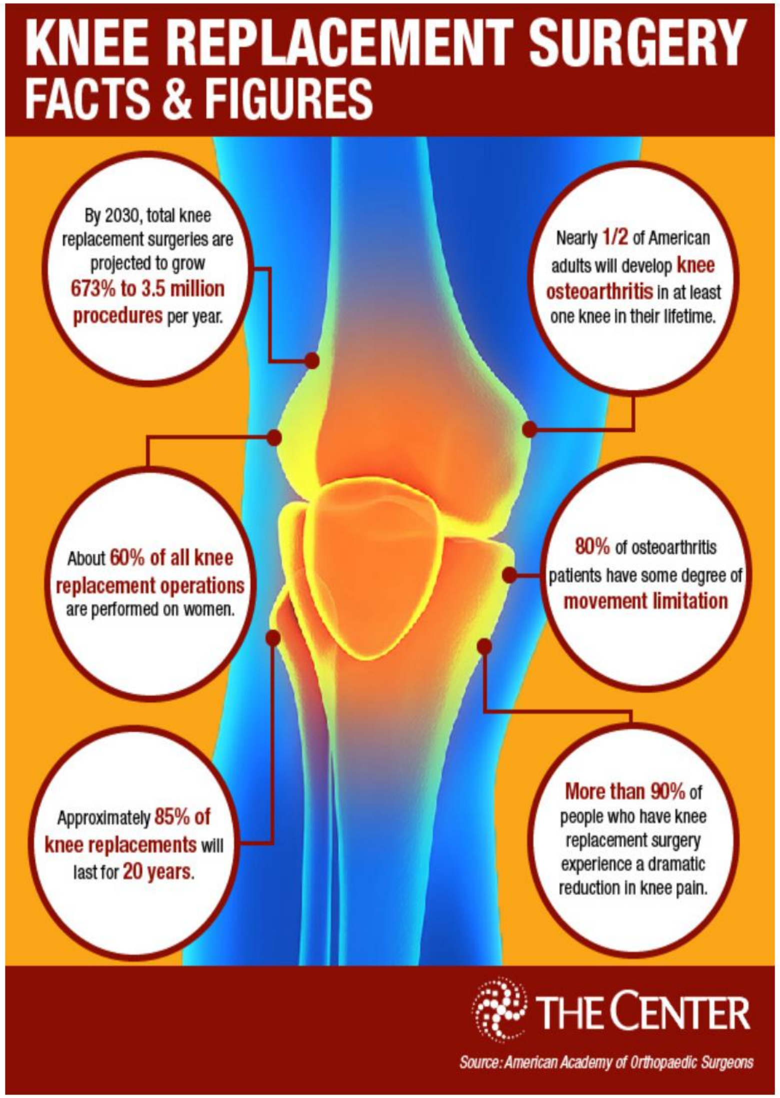
Recent Progress

- Identification of coatings capabilities.
- Identification of wear testing capabilities.
- Initial wear testing.

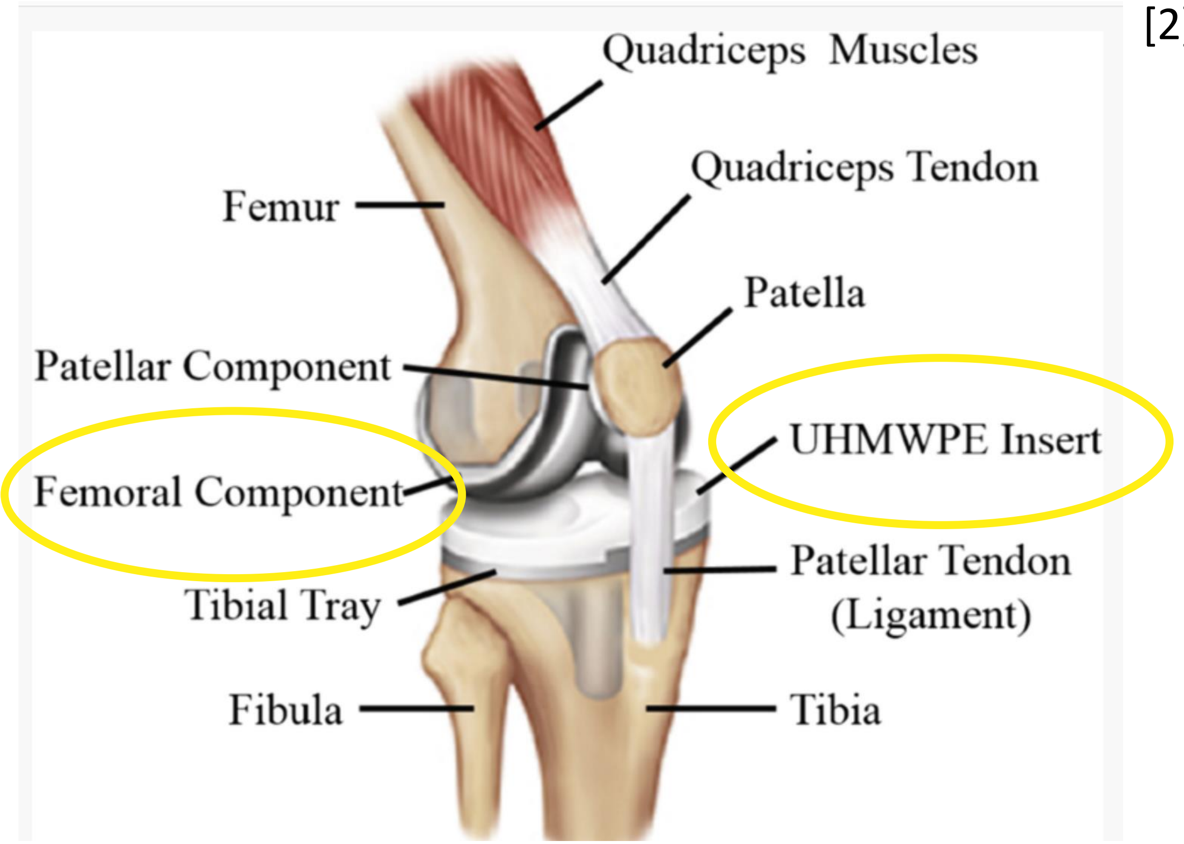
Metrics

Description	% Complete	Status
1. Literature review / Project definition	15%	●
2. Obtain base materials and testing materials	75%	●
3. Surface treatments and coatings	5%	●
4. Wear testing	5%	●
5. Fatigue testing	0%	●

Significance- Overview



[1]



[2]

- Study the femoral component implant and UHMWPE insert tribological contact

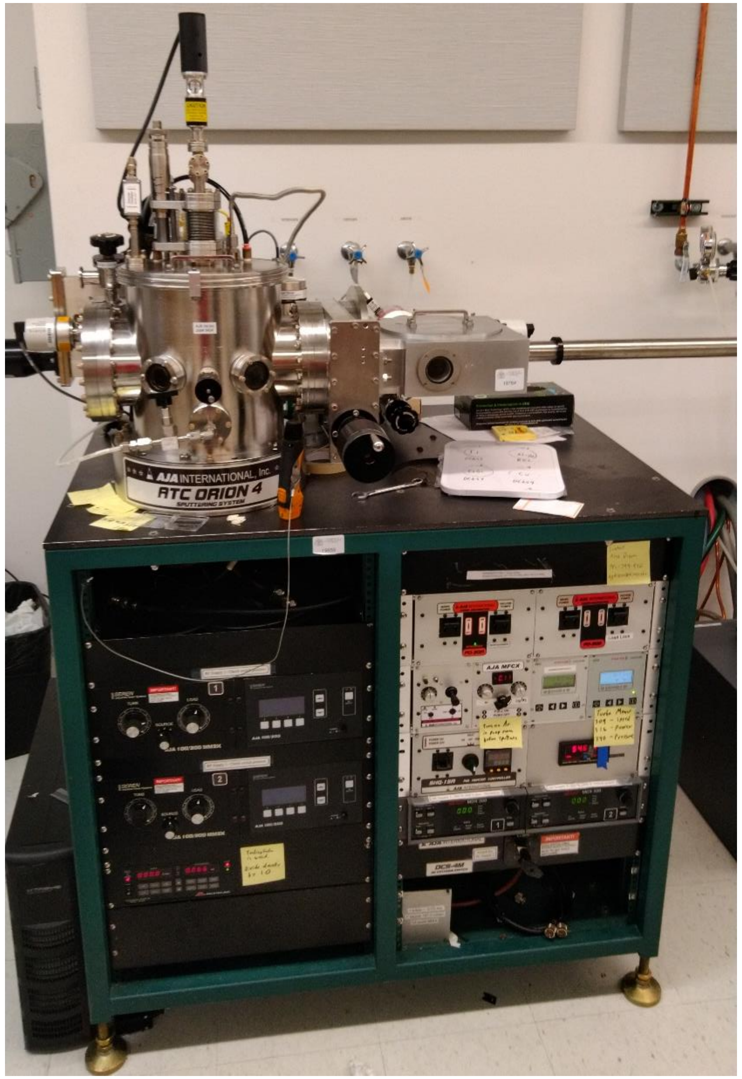
Ideal Base Material & Wear Surface Coating Properties

- **Metal Alloys and Ceramic Coating(s)**
  - Ti-6Al-4V and Ti-6Al-7Nb
  - TiN, TiNbN and ZrN
- **Low Friction**
  - Reduces wear and interface stresses
- **High Hardness & Scratch Resistant**
  - Limits indentations
- **Low Allergy**
  - Ensures compatibility
- **Adherent**
  - Avoids flaking or debris formation
- **Topologically Smooth & No Porosity**
  - Lowers wear on mating surface
- **Corrosion Resistant**
  - Decreases degradation over time
- **Cost Effective**

[3]

Coatings Capabilities

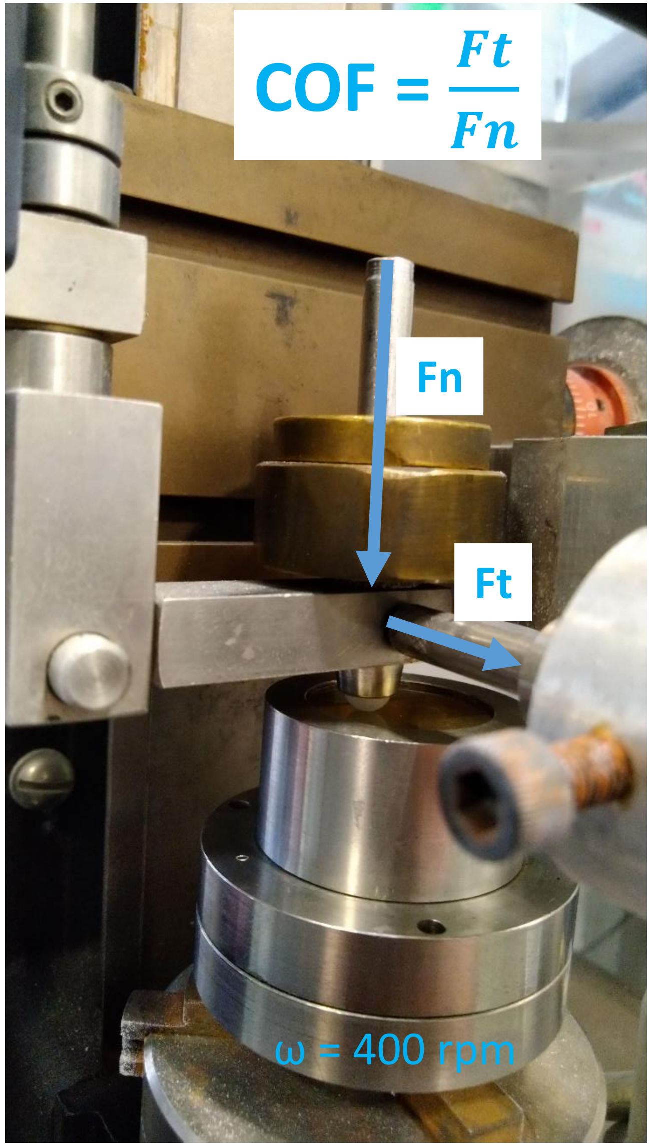
Sputtering and RF at Mines



Sputtering at Mines

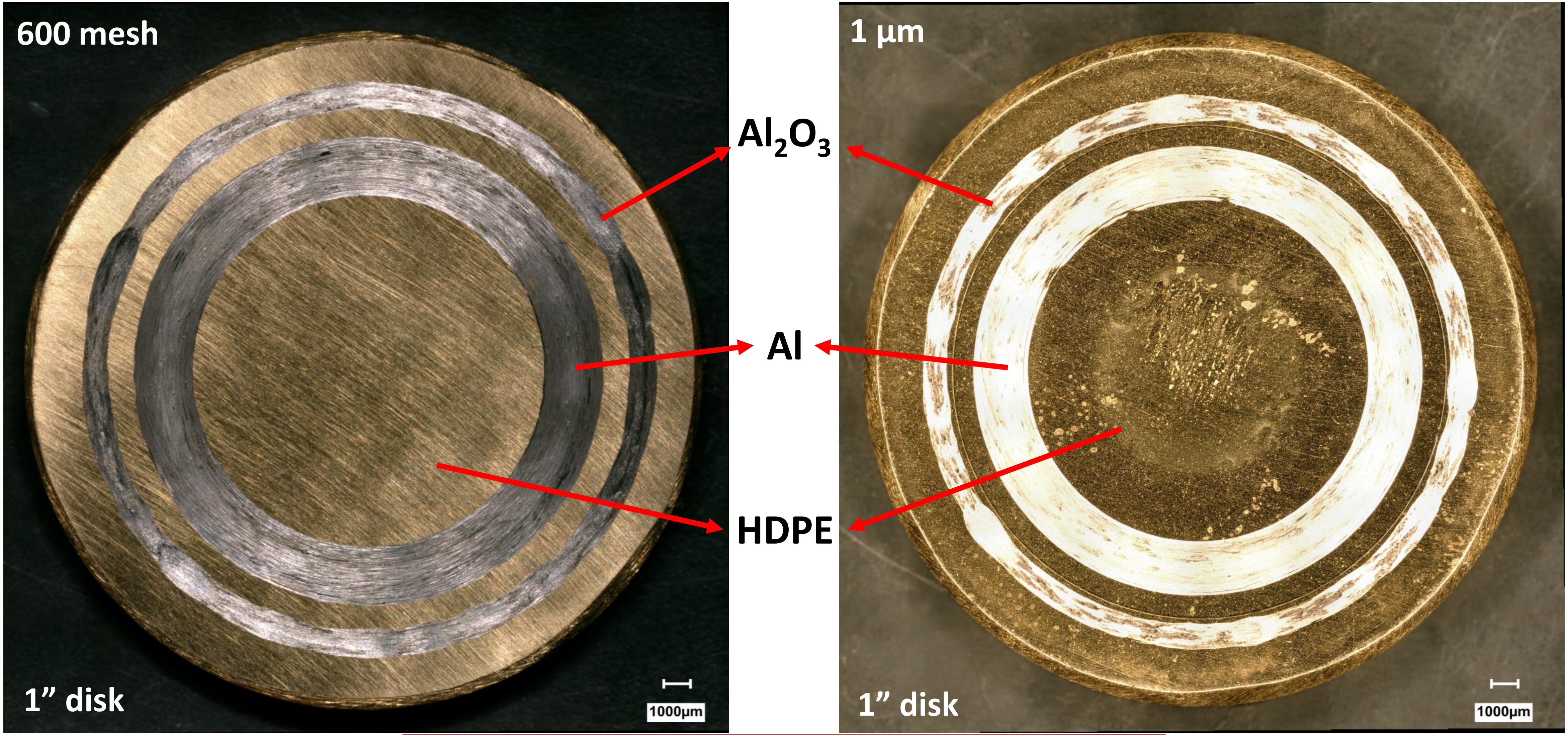
CAE at Tribologix

Wear Testing Capabilities



- Sliding wear contact to coating against
  - UHMWPE
  - Soft Metals
  - Al_2O_3 or other abrasive material
- Testing conditions
  - Dry
  - Wet submerged in artificial body fluid
  - With bone powders (dry and wet)
  - With cement powder (dry and wet)
  - With bone and cement powder mixture (dry and wet)

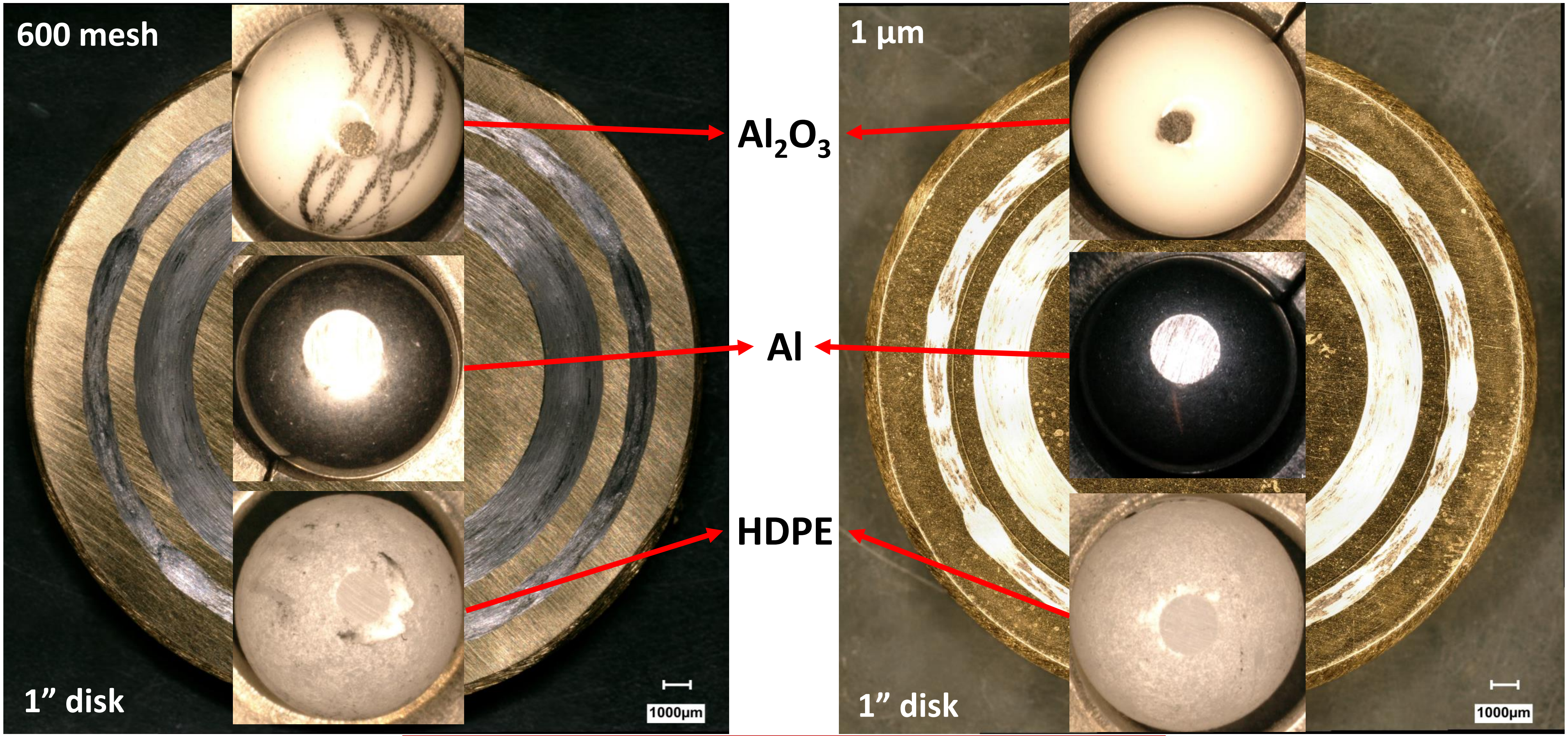
Initial Dry Wear Test Results – Baseline TiN on Ti-6Al-4V



Initial Dry Wear Test Results – Baseline TiN on Ti-6Al-4V

Ball ¼”

Ball ¼”



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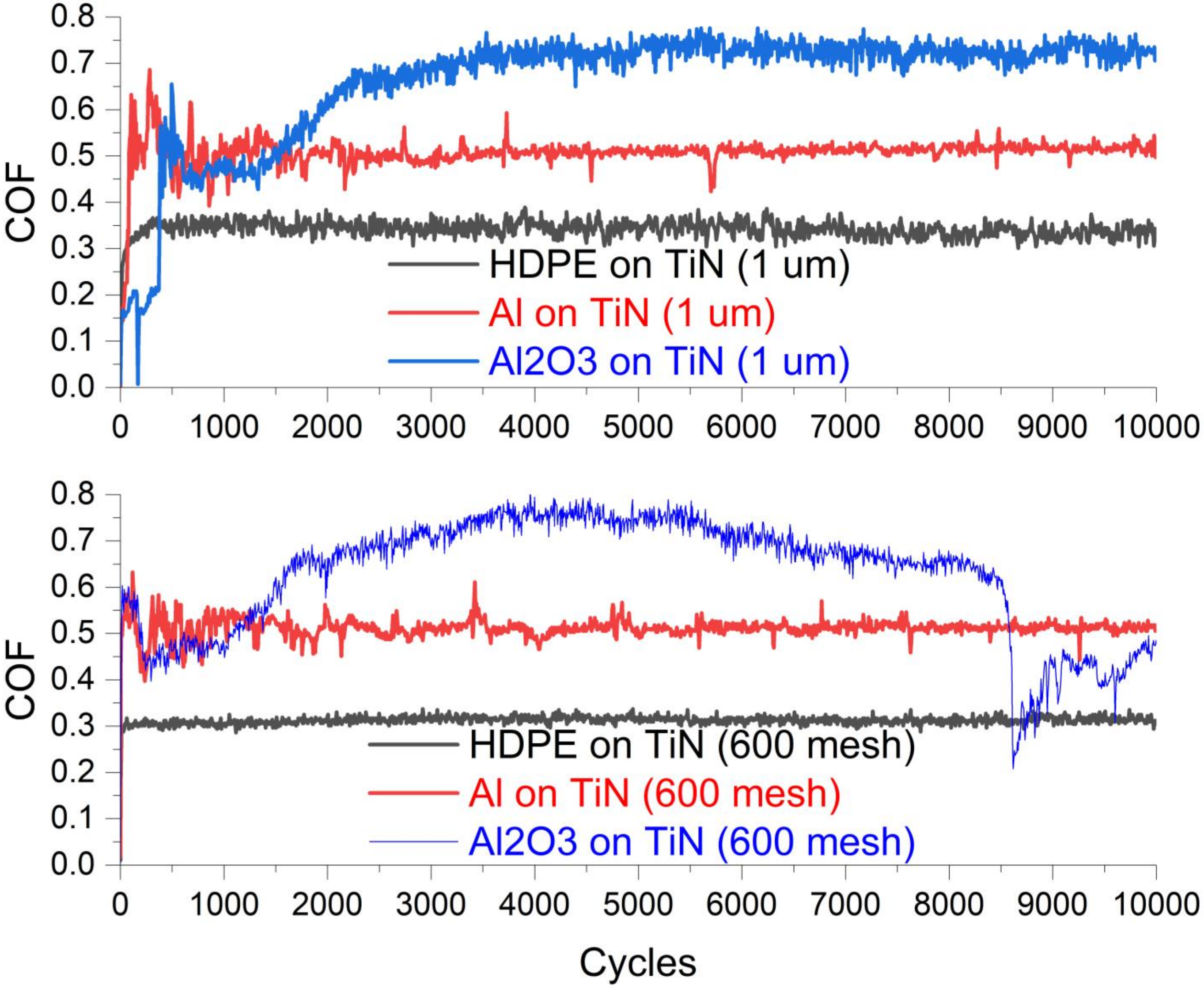
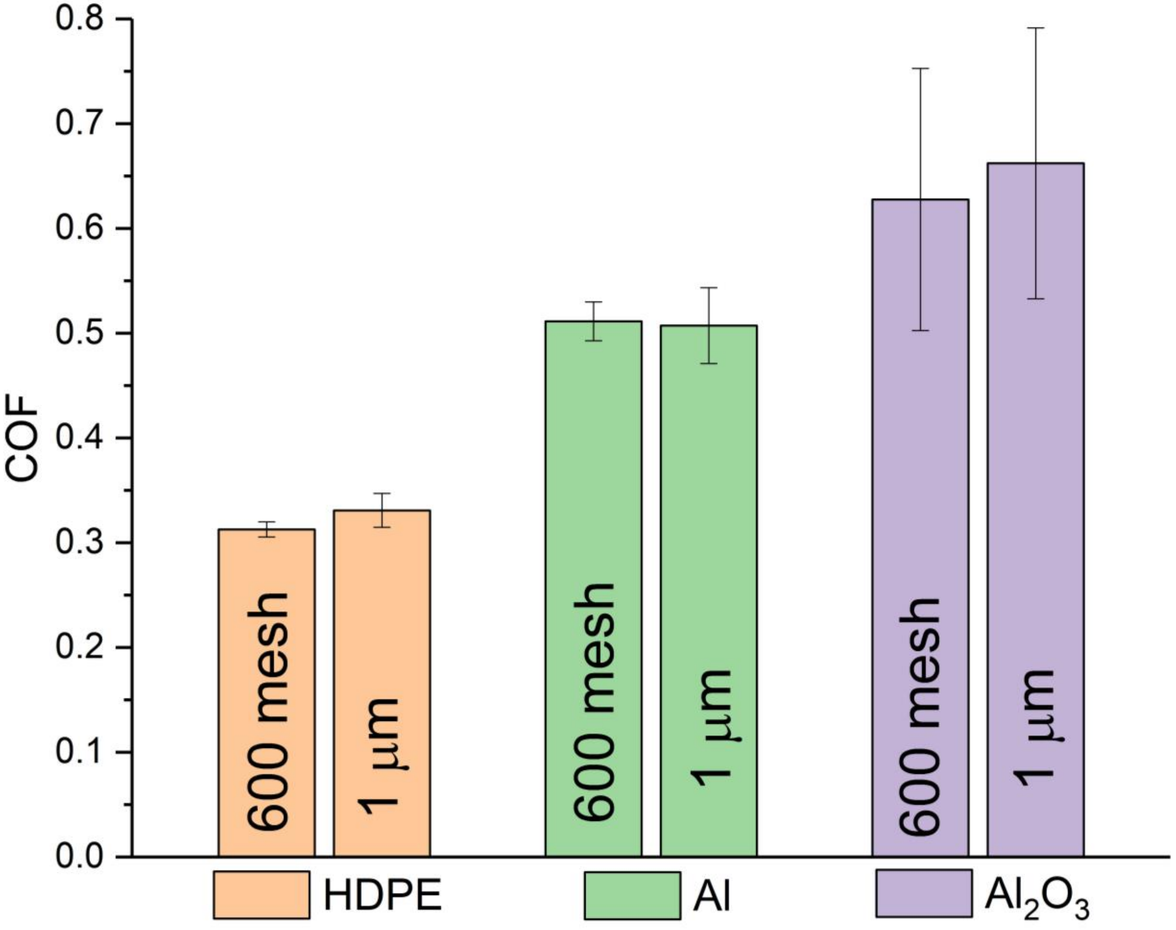


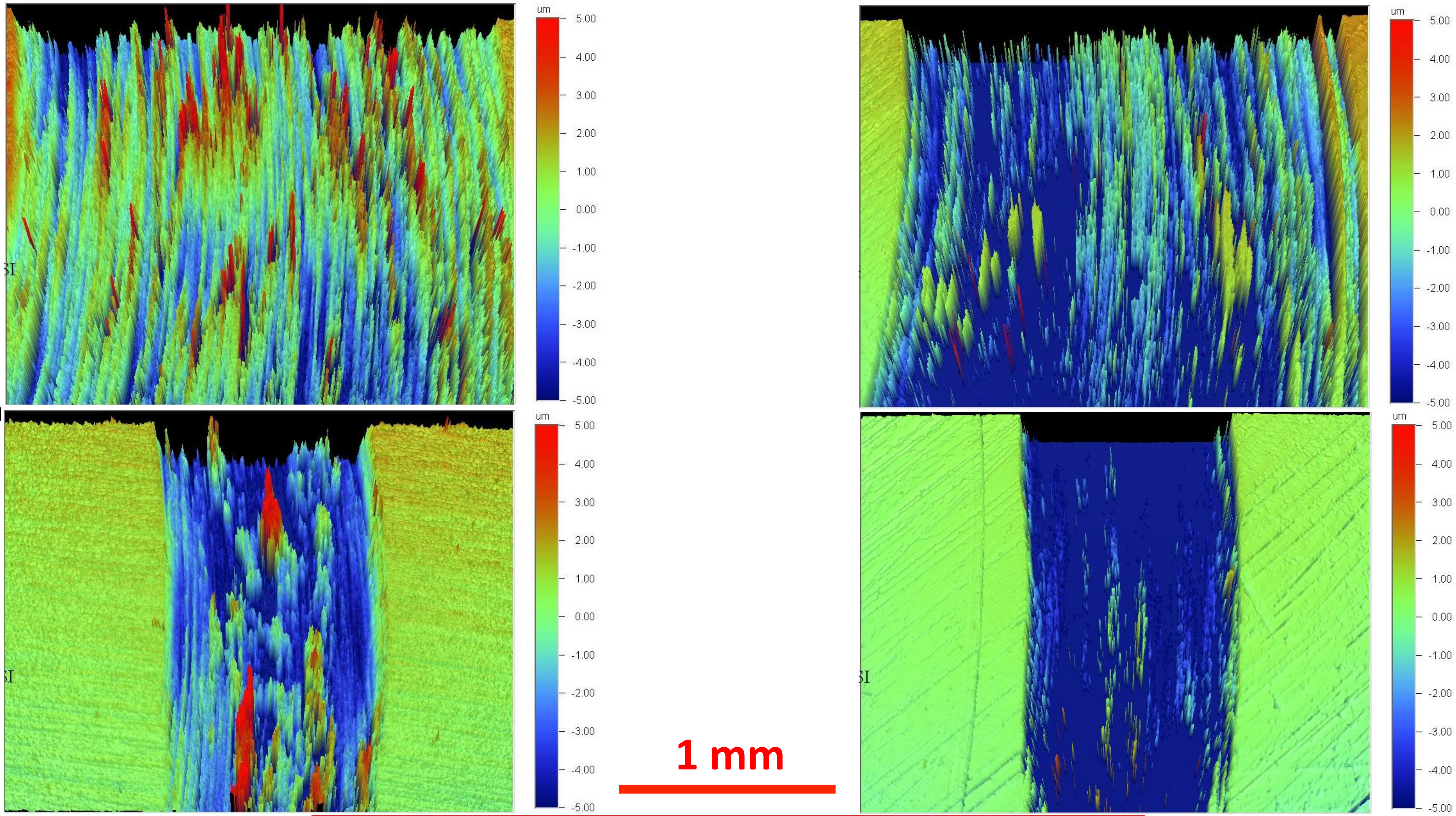


Initial Dry Wear Test Results – Baseline TiN on Ti-6Al-4V

Al ball

TiN 600 mesh

Al_2O_3 ball

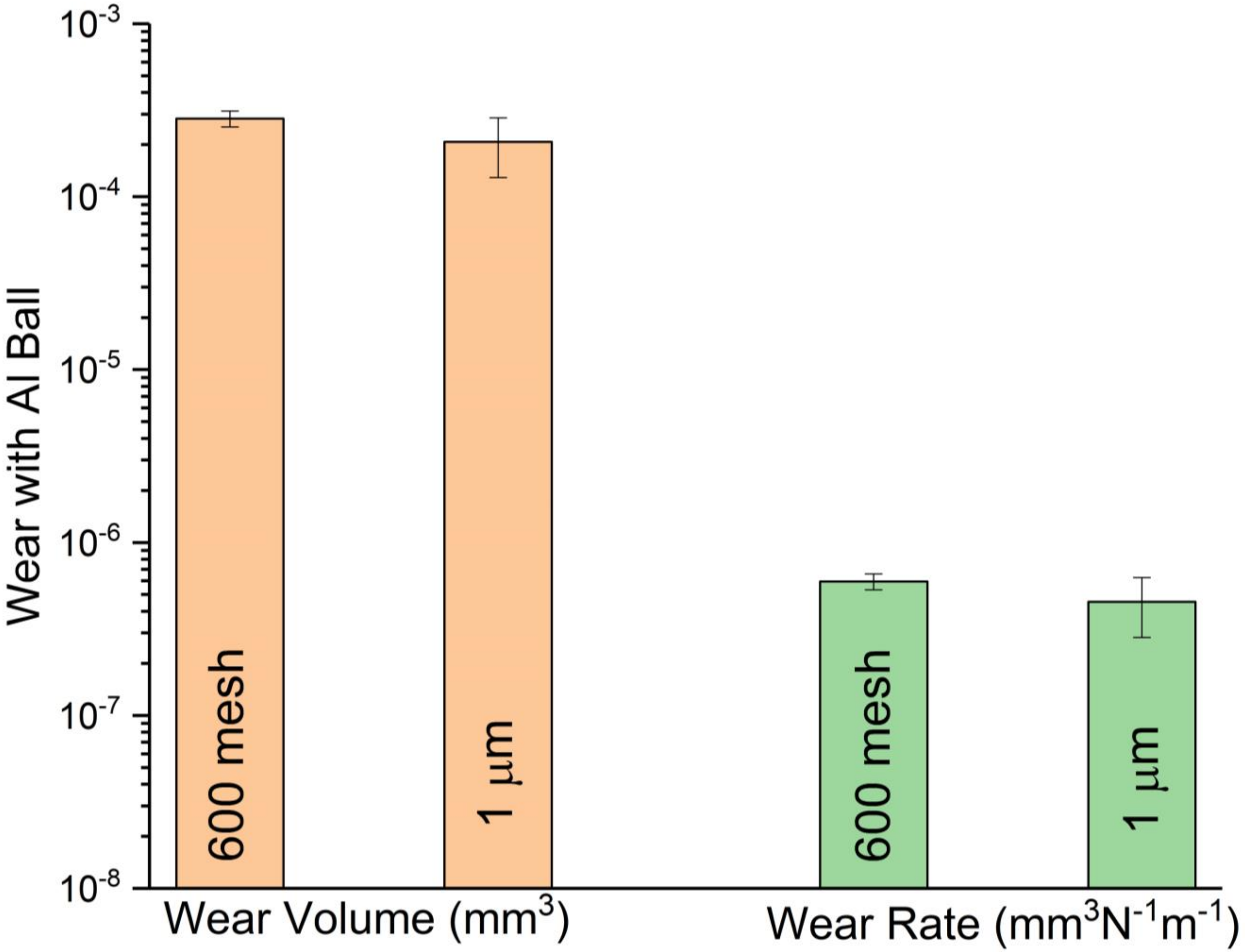


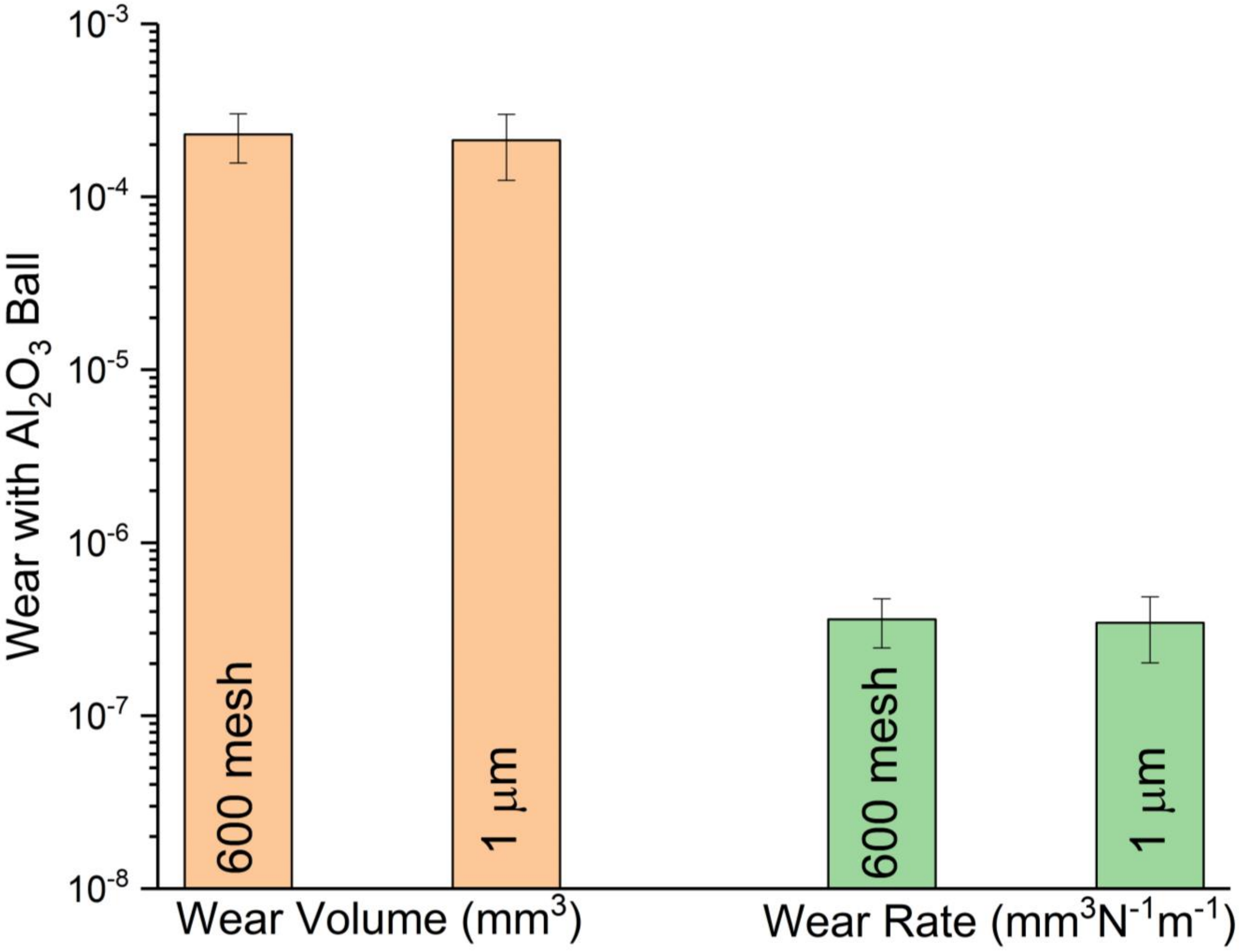
Al ball

TiN 1 µm

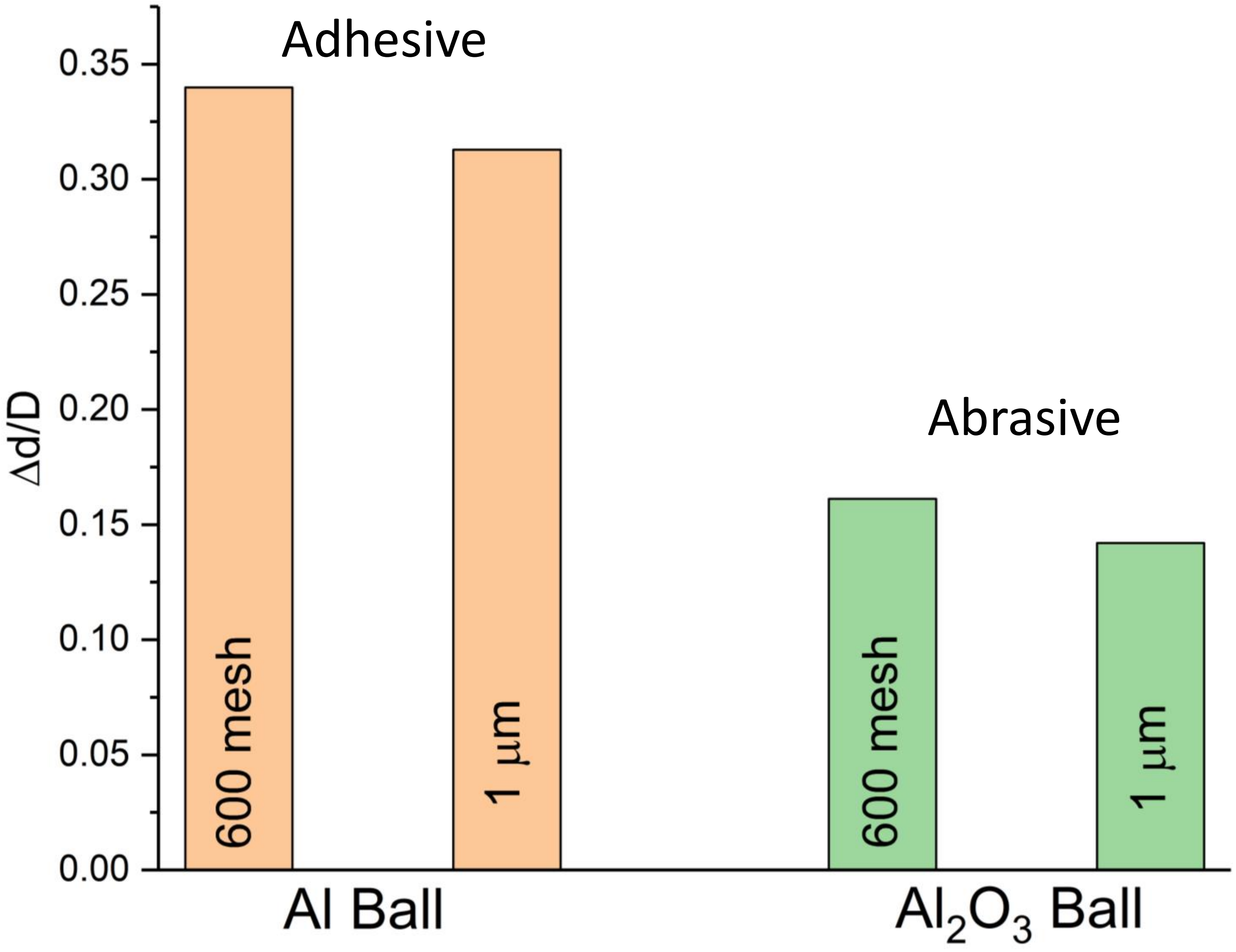
Al_2O_3 ball

Tribology Parameters – Baseline TiN on Ti-6Al-4V





Tribology Parameters – Baseline TiN on Ti-6Al-4V



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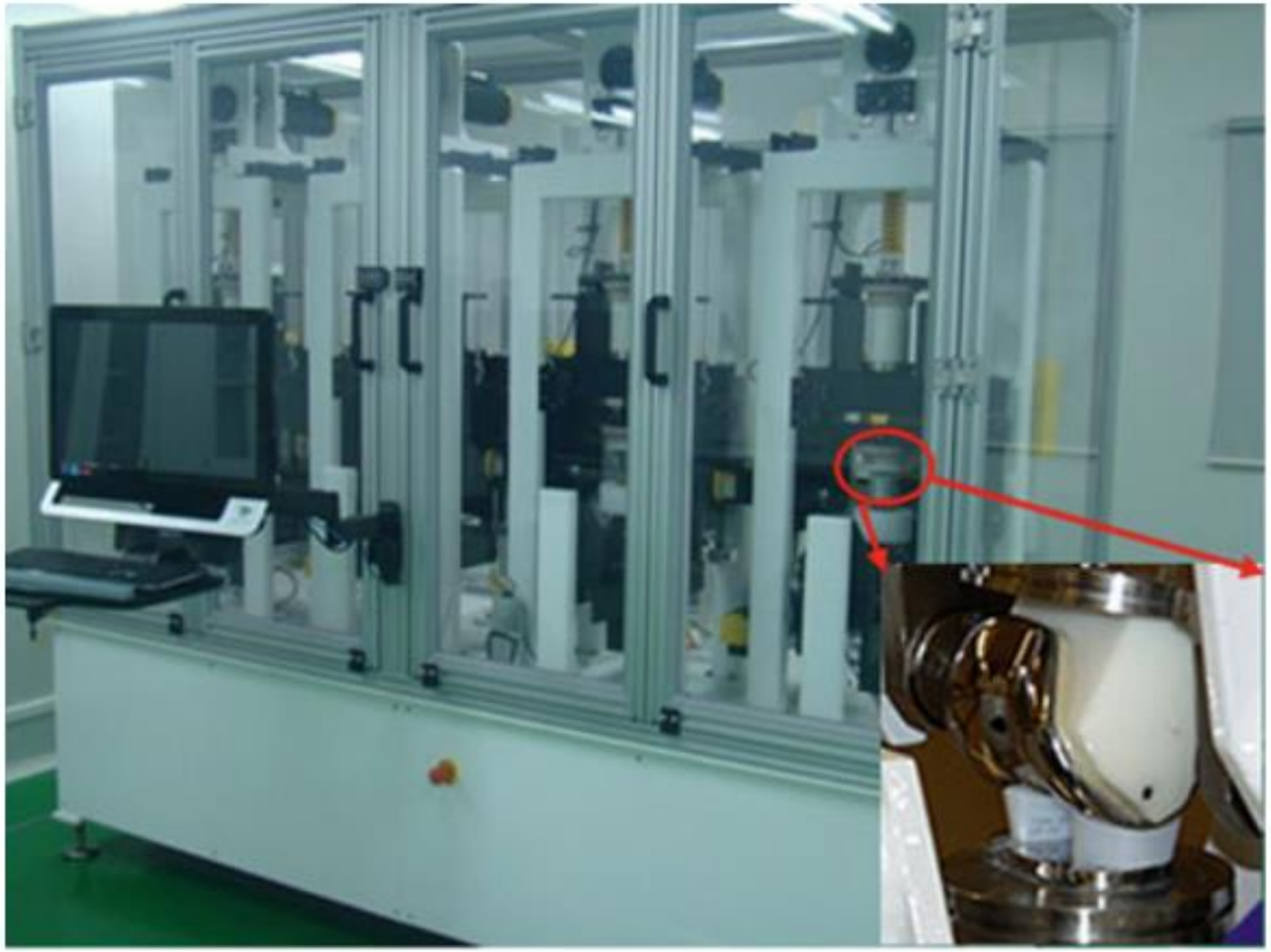
Challenges & Opportunities



[2]

- Use a knee simulator for testing best coating on the project
- Leverage from the coatings and tribology knowledge developed
  - Project 37-L: Advanced Engineered Coatings with Extended Die Life for Tooling
  - Project 54-L: Lubricious PVD Coatings for Forging Dies

References

[1] https://www.thecenteroregon.com, Orthopedic & Neuro Surgical Care and Research Science: A Notion in Motion, American Society of Orthopedic Surgeons.

[2] Jun Fu, Zhong-Min Jin, Jin-Wu Wang, UHMWPE Biomaterials for Joint Implants, Structure, Properties, and Clinical Performance, ISSN21950644, Springer Series in Biomaterials and Engineering, 2019.

[3] https://www.lincotekmedical.com/products-services/coating-solutions/physical-vapor-deposition-coatings/

Thank you!

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