Characterization of CMP Pads Containing Embedded Water Soluble Particles

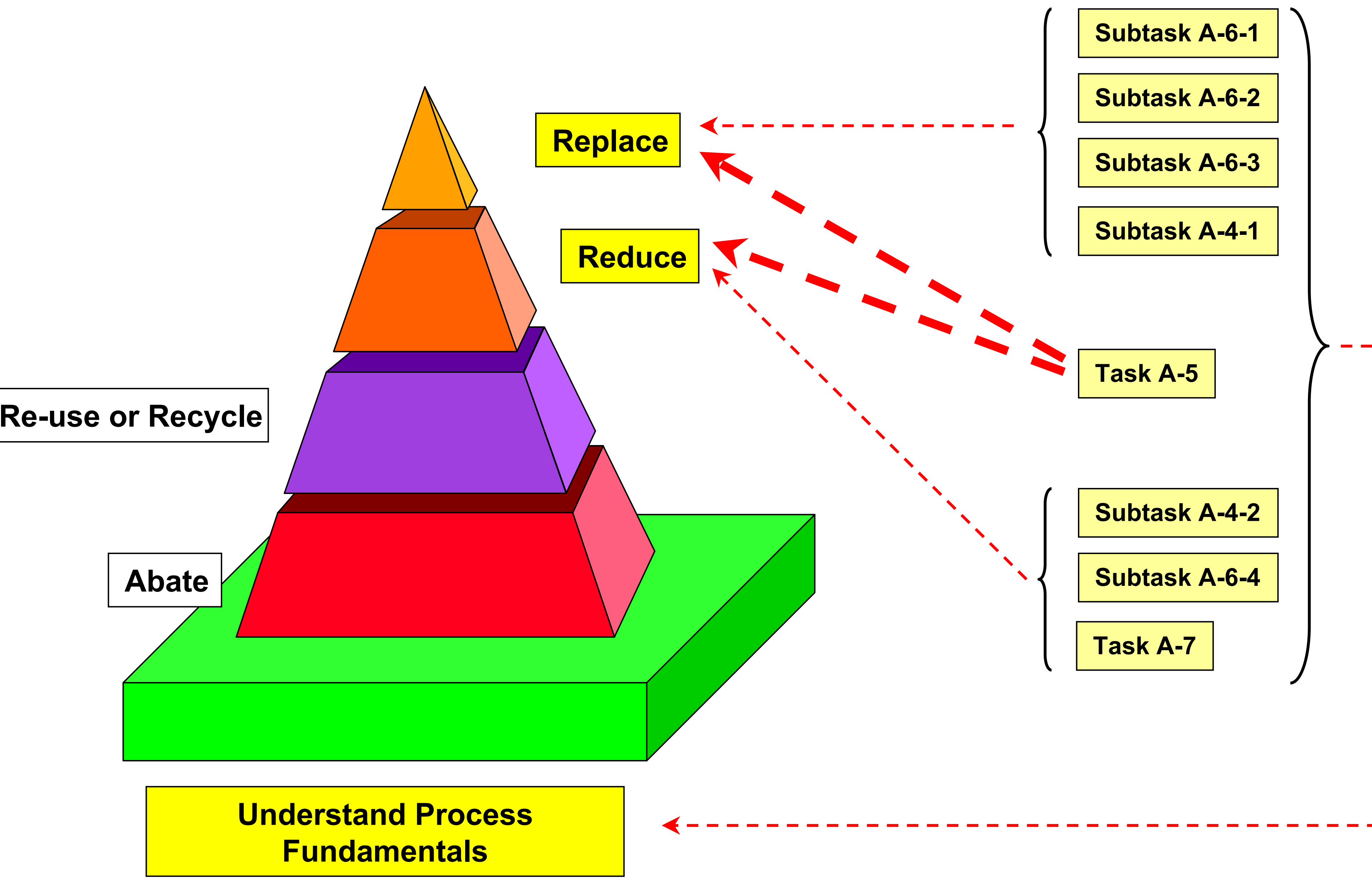
Leslie Charns & Ara Philipossian

University of Arizona
Department of Chemical & Environmental Engineering
Tucson, AZ USA

Project Sub-Task

- Task A-4: Waste minimization
  - Subtask A-4-1: Modeling of pattern dependency effects (Boning)
  - Subtask A-4-2: Fluid dynamics analysis and tribological characterization (Philipossian)
- Task A-5: Fundamental pad characterization and modeling (Philipossian & Beaudoin)
- Task A-6: Alternative planarization technologies
  - Subtask A-6-1: Fixed abrasive pads (Raghavan)
  - Subtask A-6-2: Abrasive free slurries (Boning)
  - Subtask A-6-3: Coupled plating and planarization processes (Boning)
  - Subtask A-6-4: Controlled-atmosphere planarization (Philipossian)
- Task A-7: Post-planarization waste minimization (Philipossian)

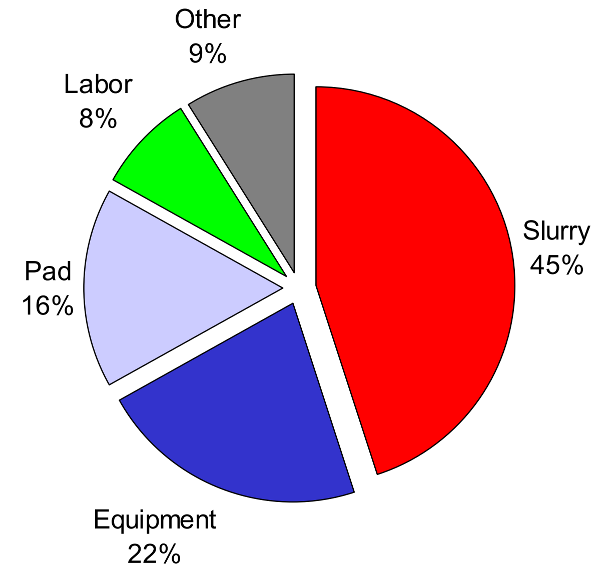
Planarization Team & the EHS Pyramid



Overall Motivation

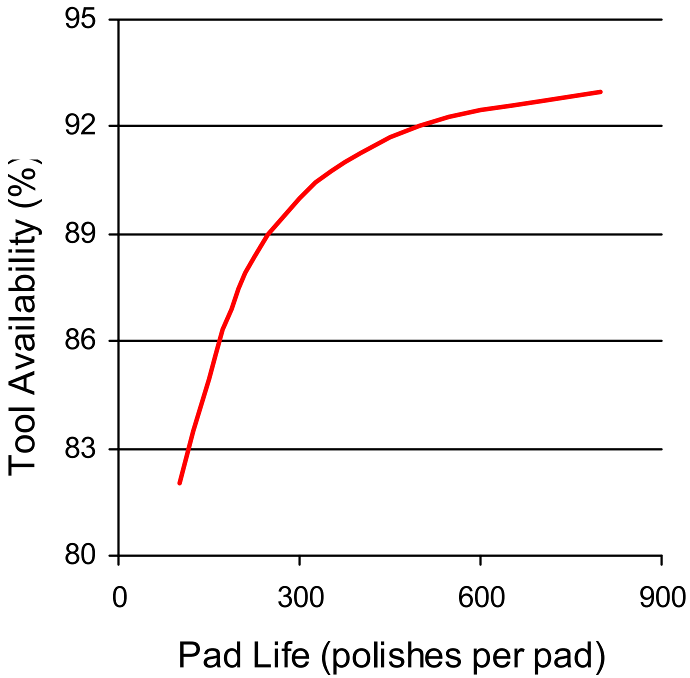
Slurry is the largest contributor to CMP COO (8000 WSPW, 200-mm factory, 5 Cu layers):

- ~ 6,000,000 liters of slurry per year
- ~ 20,000,000 USD of slurry per year
- ~ 300 metric tons of solid waste per year
- ~ 400,000,000 liters of UPW per year



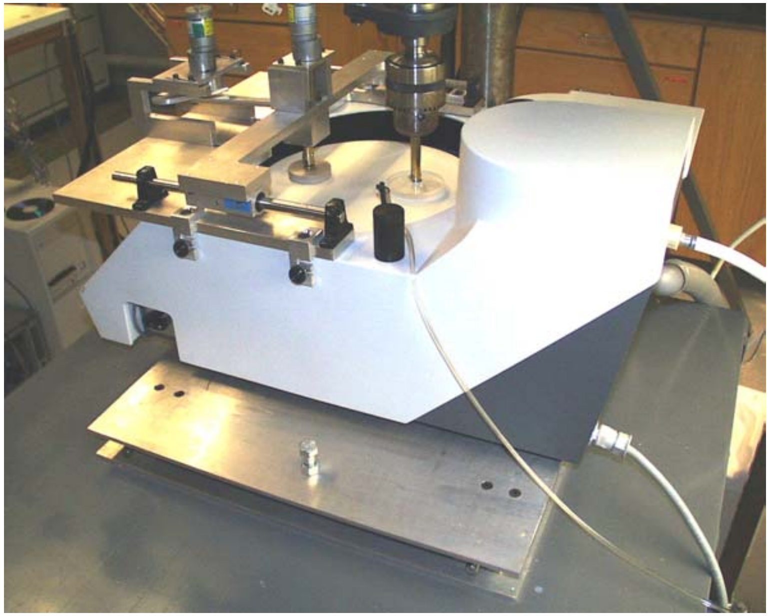
Increasing pad life will lead to:

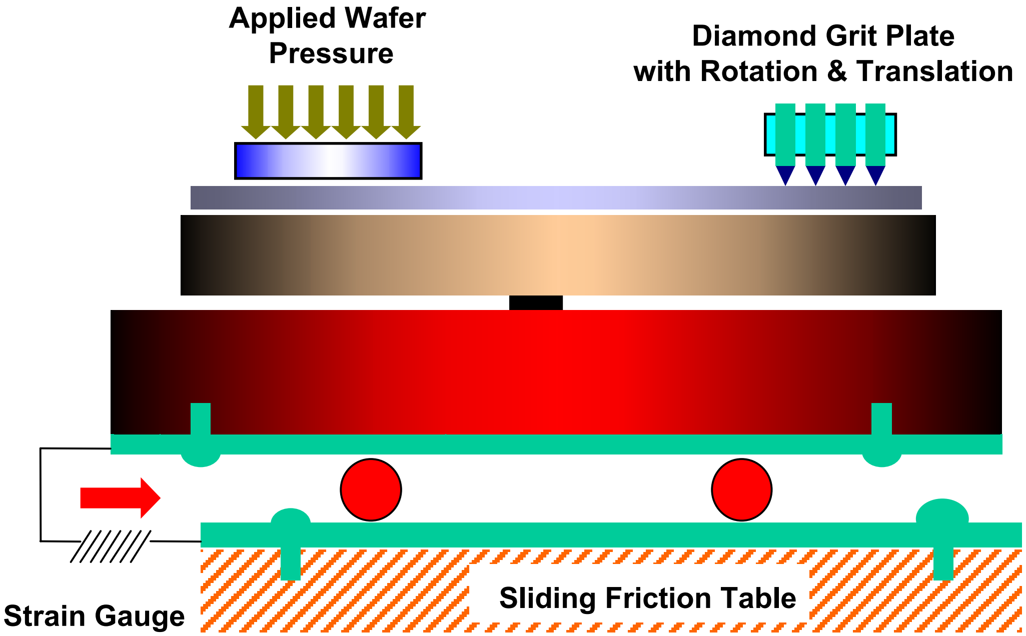
- Reduced pad consumption
- Increased polisher availability
  - (i.e. capital cost avoidance)
- Reduced monitor wafer consumption
  - (and consumables associated with polisher re-qualification)



Apparatus

Parameter	Scaling Factor	Speedfam-IPEC 472	Rotopol-35
Down Pressure	1	4 psi	4 psi
Platen Speed	Reynolds Number	Relative pad-wafer velocity of 0.5 m per second (30 rpm)	Relative pad-wafer velocity of 0.5 m per second (55 rpm)
Platen Diameter / Wafer Diameter	D_{platen} / D_{wafer}	51 cm / 15 cm	31 cm / **9 cm**
Platen Diameter / Wafer Diameter	D_{platen} / D_{wafer}	51 cm / 20 cm	31 cm / **12 cm**
Slurry Flow Rate	Platen Surface Area	175 cc per minute	65 cc per minute

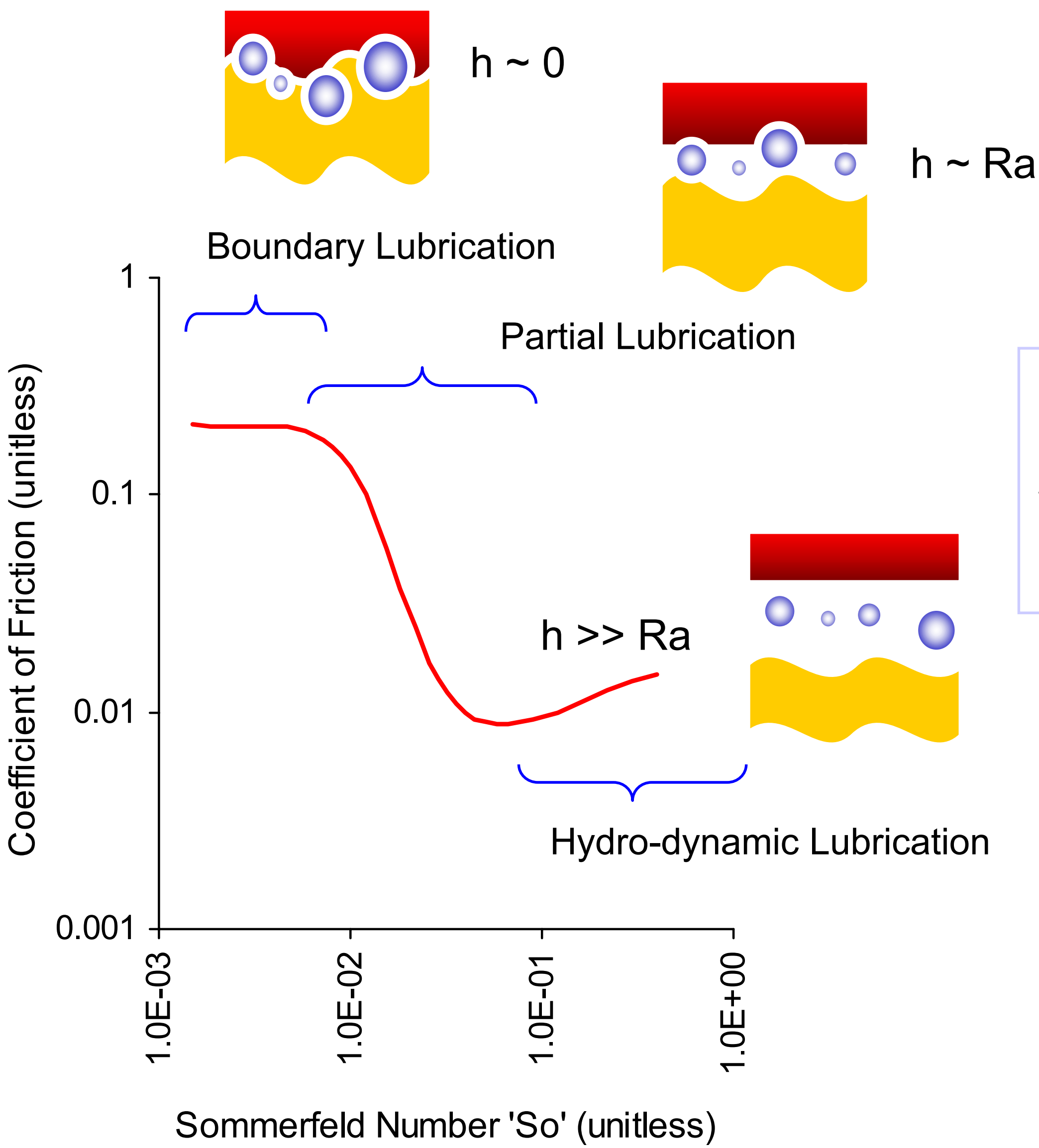




Apparatus

$$COF = \frac{F_{shear}}{F_{normal}}$$

Lubrication Theory and the CMP Process



Slurry viscosity … **Dependent on slurry type & abrasive concentrati** **(physically measured)**

Relative pad-wafer velocity … **Dependent on polisher geometry**

$$So = \frac{(V) \times (\mu)}{(P_{app}) \times (Ra)}$$

Applied pressure

Pad surface roughness (measured by profilometry)

Removal Rate Equation

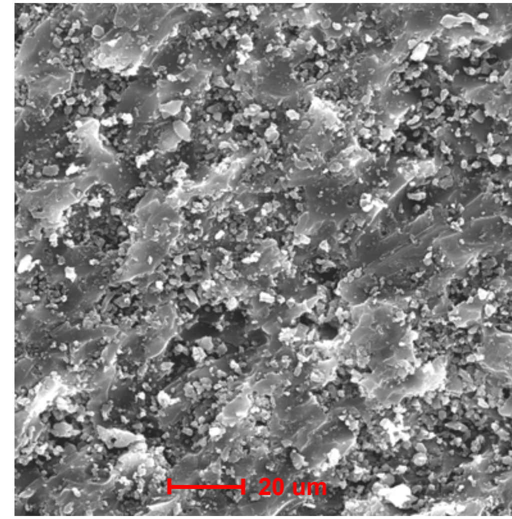
Preston Equation

$$Removal\ Rate = (k_m k_c)(P)(V)$$

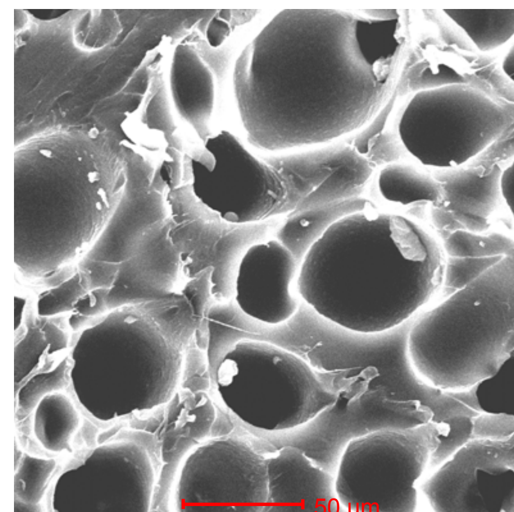
- The removal rate was plotted against (Pressure * Velocity)
- The slope obtained is the rate constant (k-value = km * kc)
  - km = mechanical rate constant
  - kc = chemical rate constant
- Error bars in the Removal Rate charts correspond to +/- 1 sigma

Motivation

- To characterize a novel pad design that incorporates water soluble particles (WSP) embedded in the pad composition as it relates to:
  - Pad decay as a result of conditioning and glazing
  - Tribology
  - Removal Rate
  - Temperature
    - Temperature increase of the bow wave
    - Temperature increase of the pad
- To perform a comparative analysis of:
  - Commercial pad to JSR pads
    - Fixed porosity vs. controlled porosity



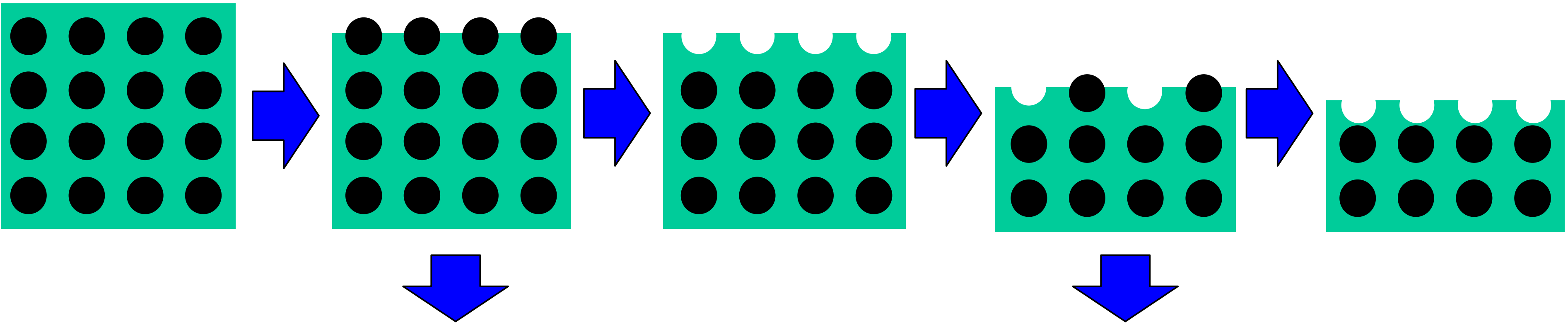
JSR Pad with WSP (new)
Controlled Porosity Pad

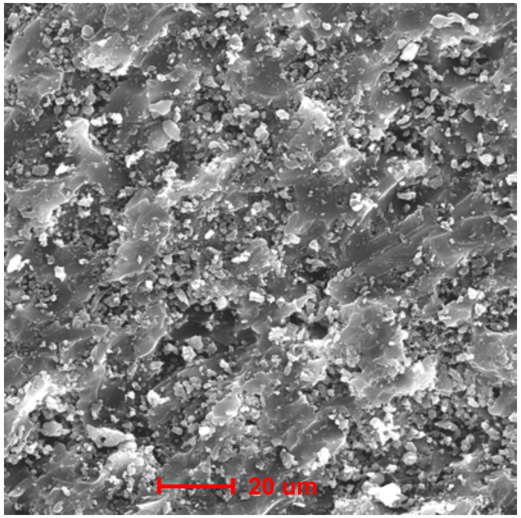


Rodel IC-1000 (new)

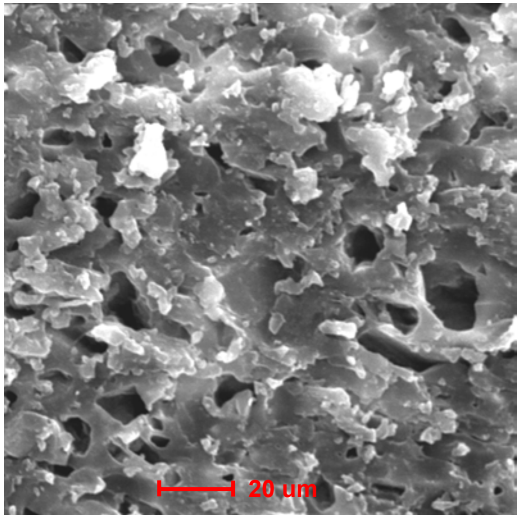
Process of Surface Self Regeneration via WSP

JSR Self-Regenerating Pads with Controlled Porosity





JSR Pad with Std WSP (new)

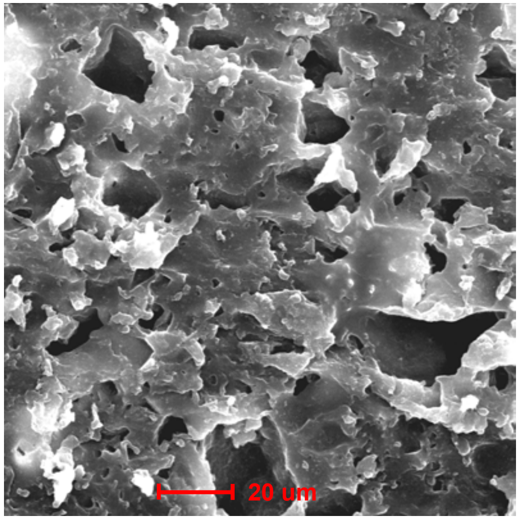


JSR Pad with Std WSP (used)

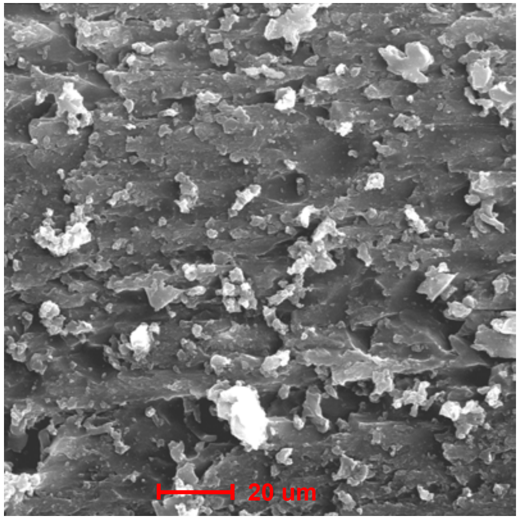
Pad Descriptions

Pads (all are k-grooved)

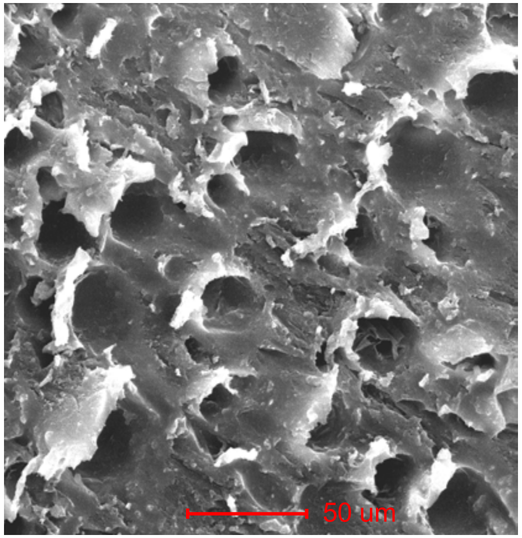
- JSR Standard WSP
- JSR No WSP
- JSR High WSP
- JSR Standard WSP
  - lower matrix hardness
- Rodel IC-1000



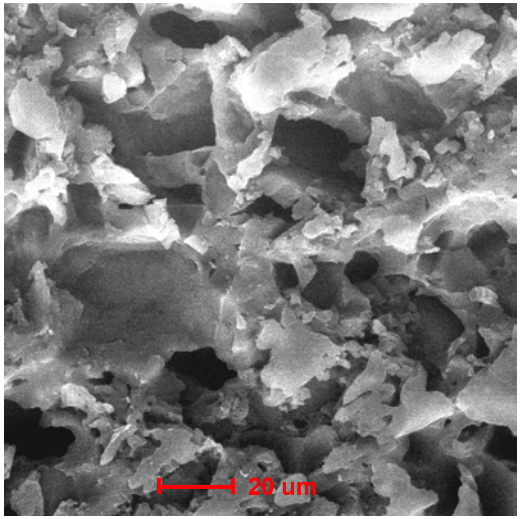
Standard WSP



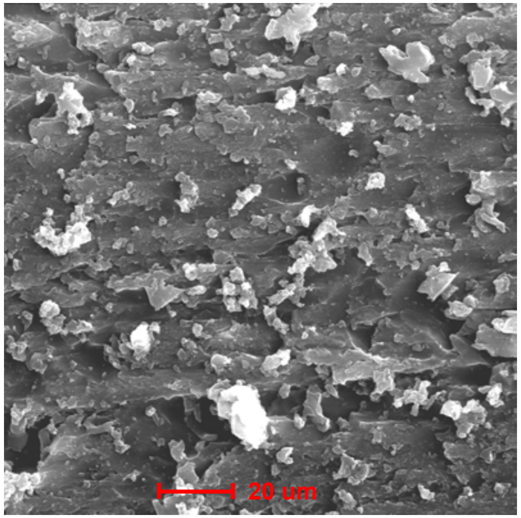
No WSP



Rodel IC-1000



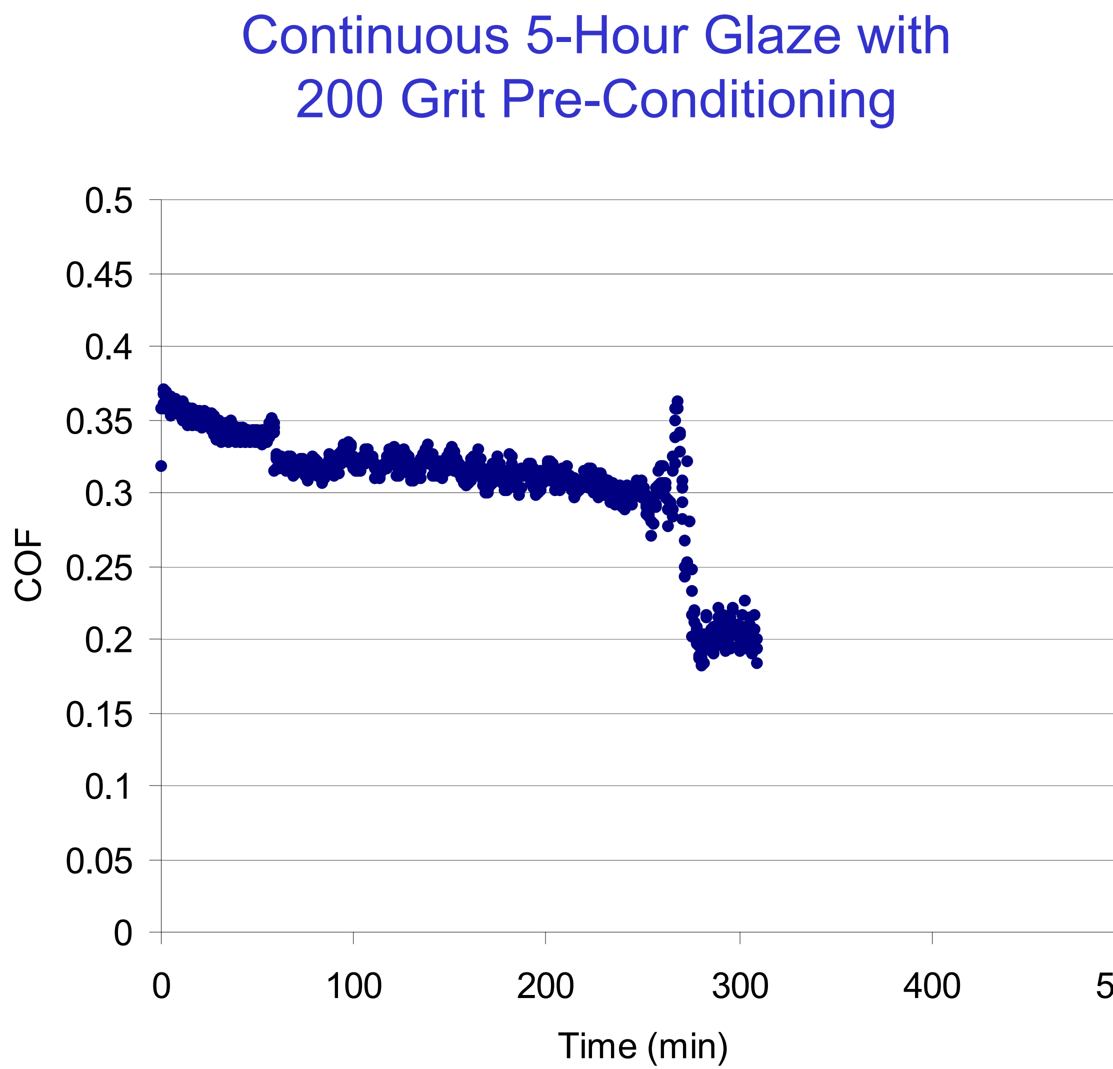
High WSP



Std WSP – Low Matrix

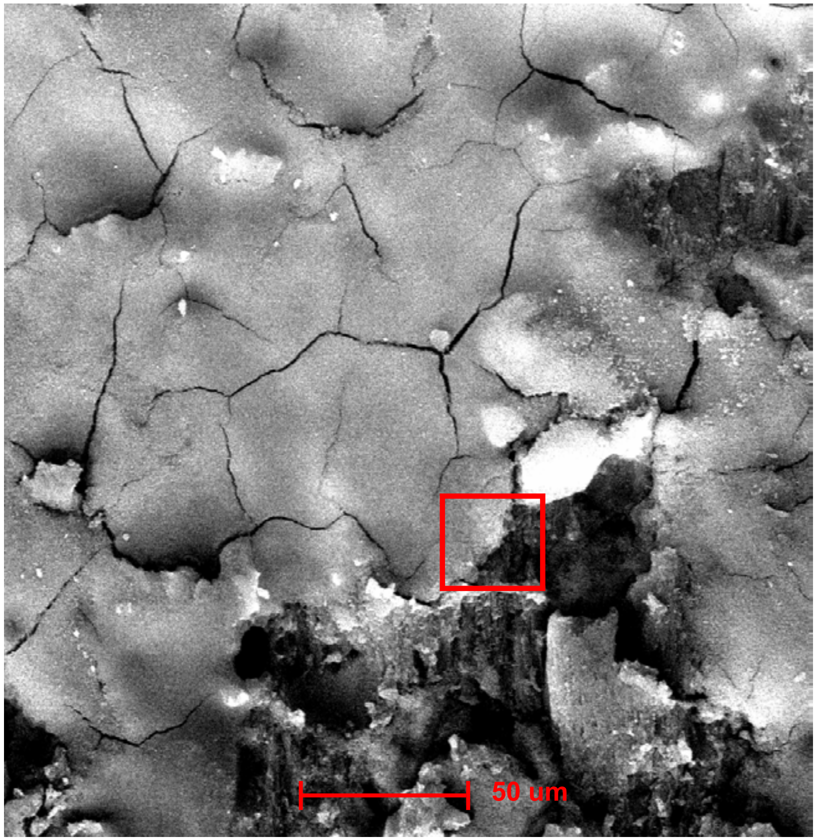
Pad Glazing

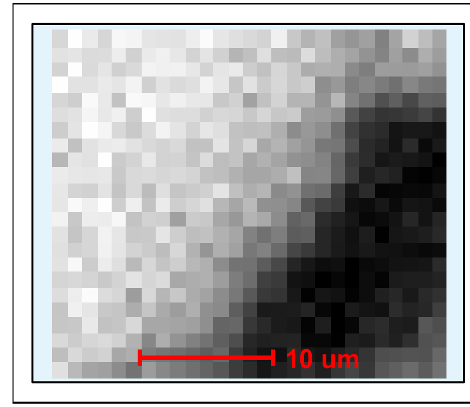
- Pad Glazing
  - During polishing, the cavities and pores on the surface of a pad will get filled with slurry
  - Due to the pressure and temperature increase during polishing, the slurry starts to “glaze” the pad, or in other words, precipitate on the pad
  - Pad glazing is a method to test the decay of a pad. It determines when a pad starts to decay and the rate of its decay



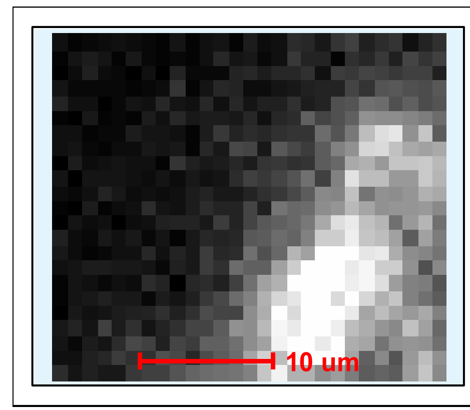
X-Ray Analysis - Elemental Images

Continuous 5-Hour Glaze with 200 Grit Pre-Conditioning

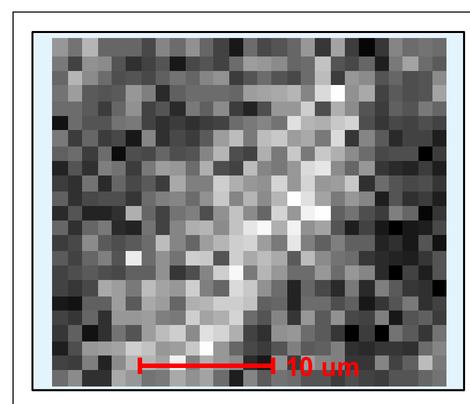




silicon



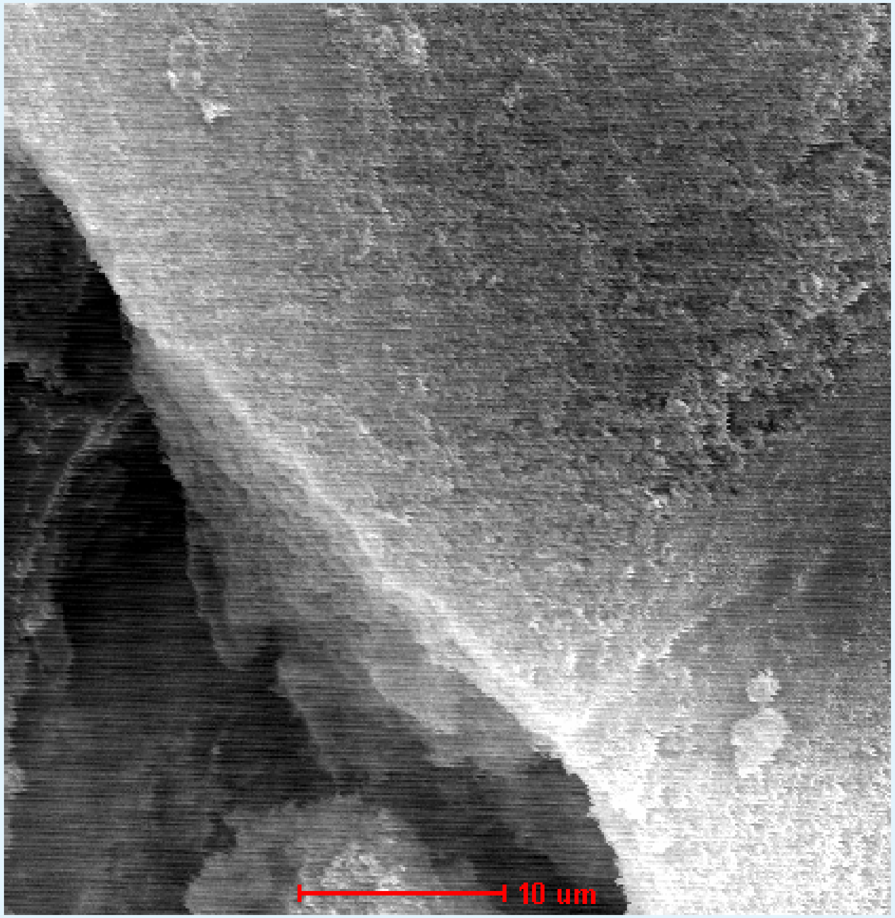
carbon



oxygen

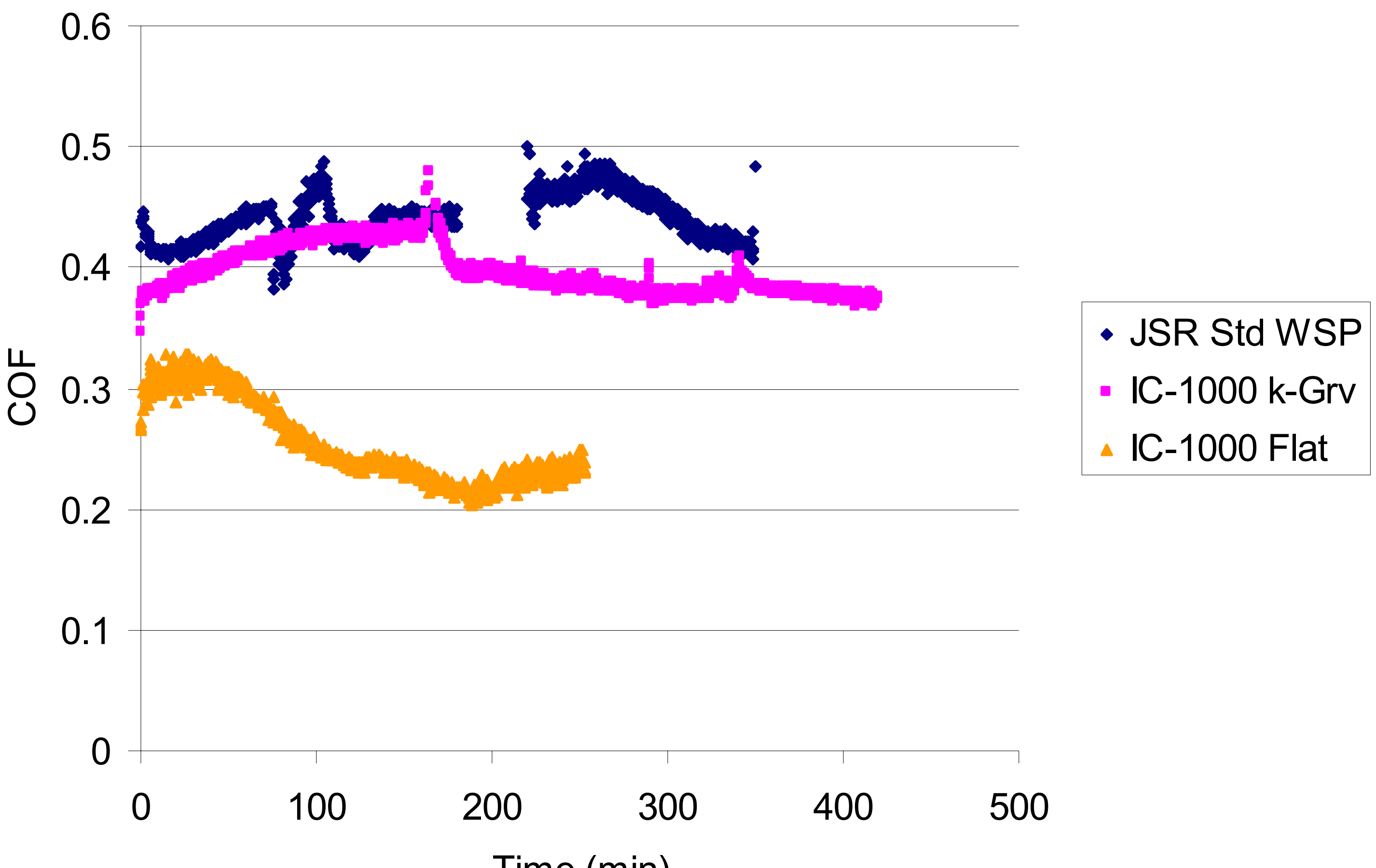
- Area Scan for Compositional Images
  - Scan over glazed region and exposed pad
  - Brightness on the compositional image corresponds to high signal of

Approximate Thickness of Glazed Layer

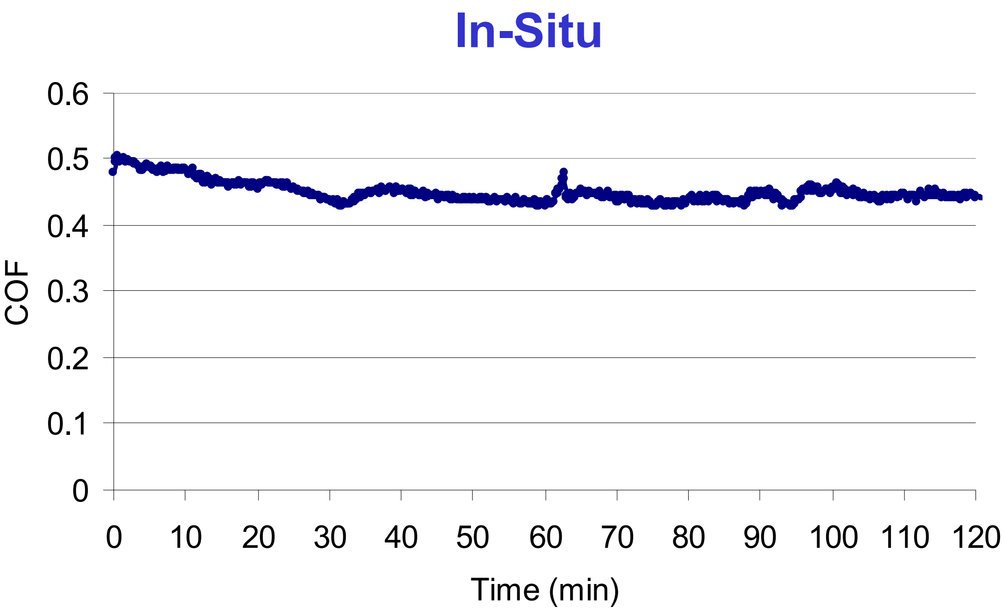


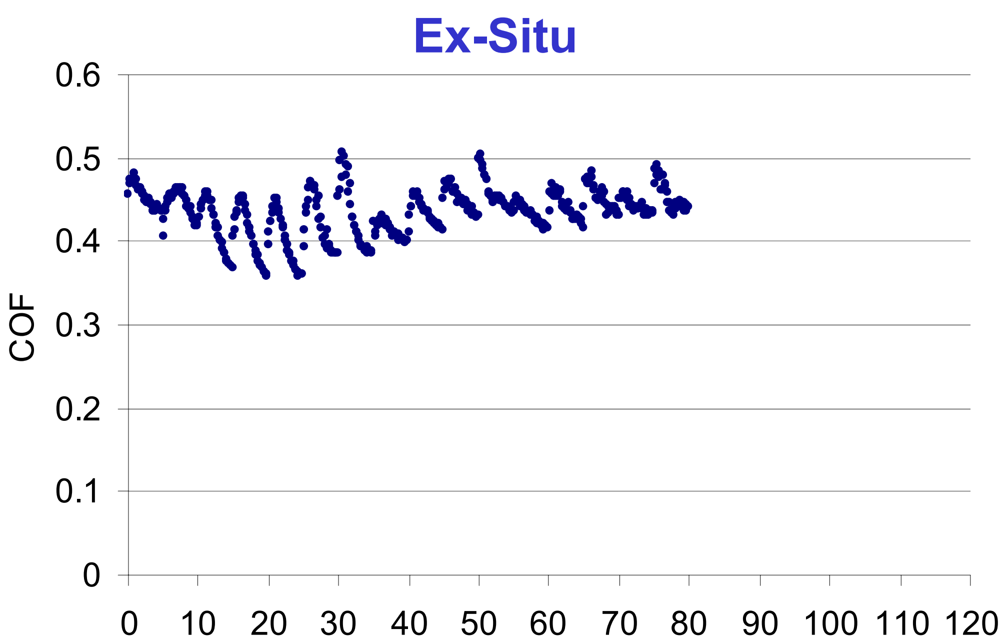
Pad Glazing JSR Standard WSP

- COF is constant for JSR standard grooved and IC-1000 k-groove pads during glazing
- IC-1000 Flat pad demonstrates a decrease in COF while glazing



Pad Decay In-Situ vs. Ex-Situ Conditioning





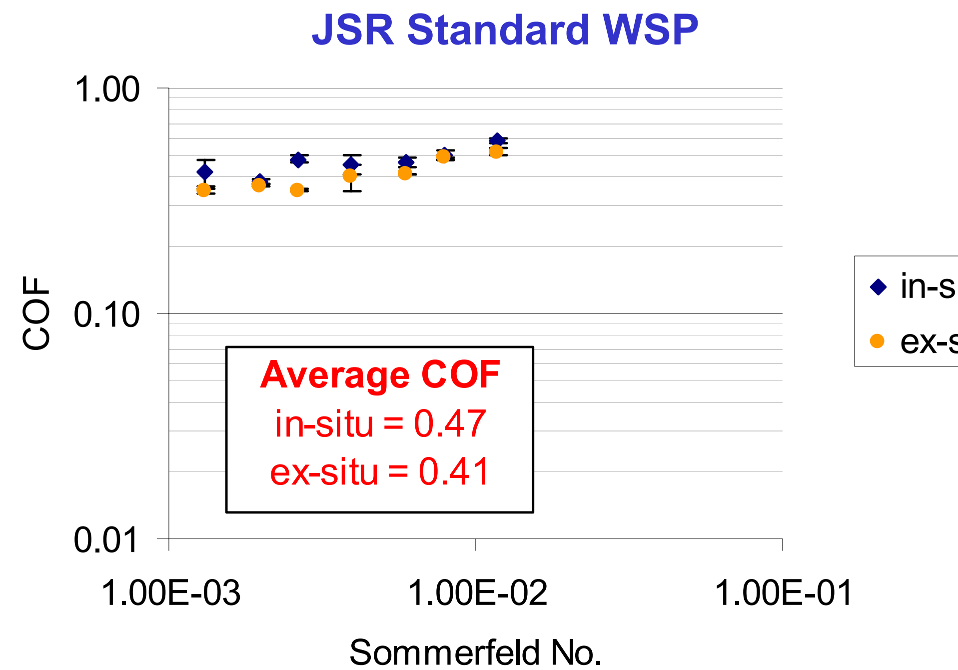
- In-situ
  - Conditioned pad and polished wafer in-situ for 90 min
- Ex-situ
  - Polished wafer for 5 minutes with no conditioning
  - Conditioned pad for 5 minutes with no polishing
  - Repeat until total polishing time is 90 minutes and total conditioning time is 90 minutes

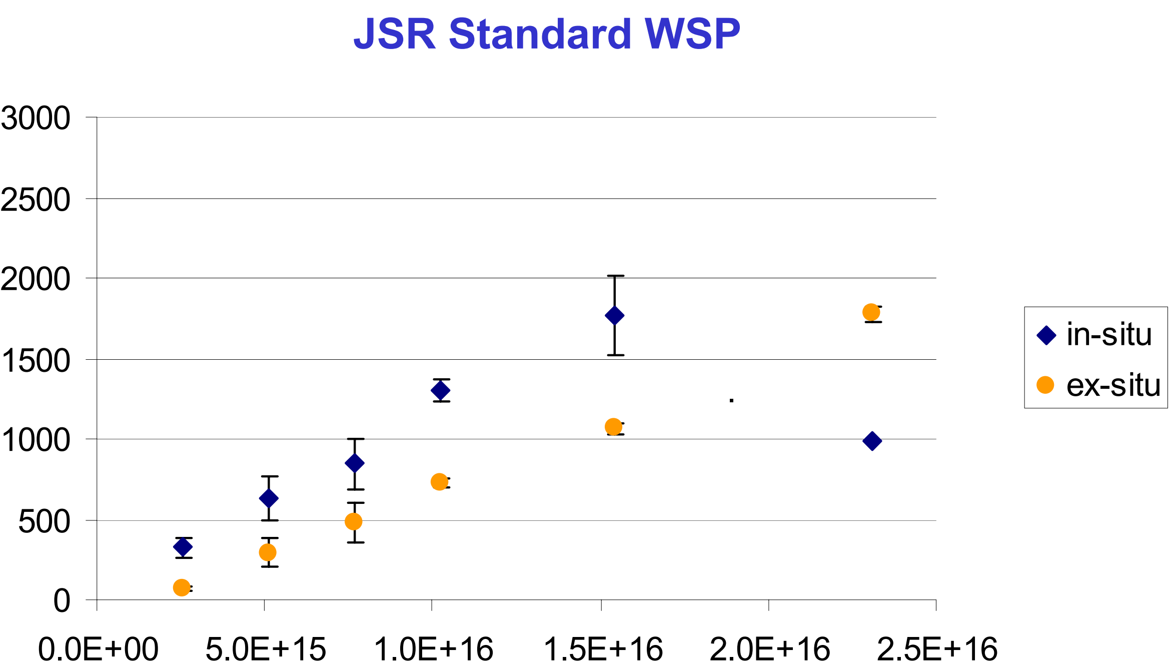
Tribology & Removal Rate

JSR Standard WSP Pad

- Lubrication Region
  - Grooved pads exhibit boundary lubrication for the entire range of Sommerfeld Numbers tested

$$So = \frac{(u) \times (\mu)}{(P_{app}) \times (Ra)}$$

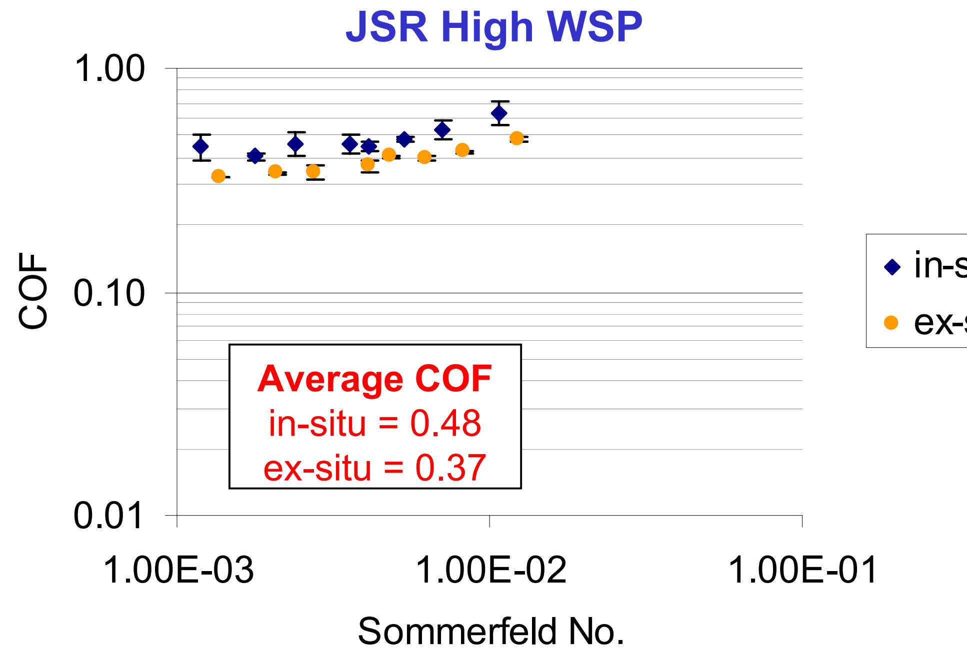


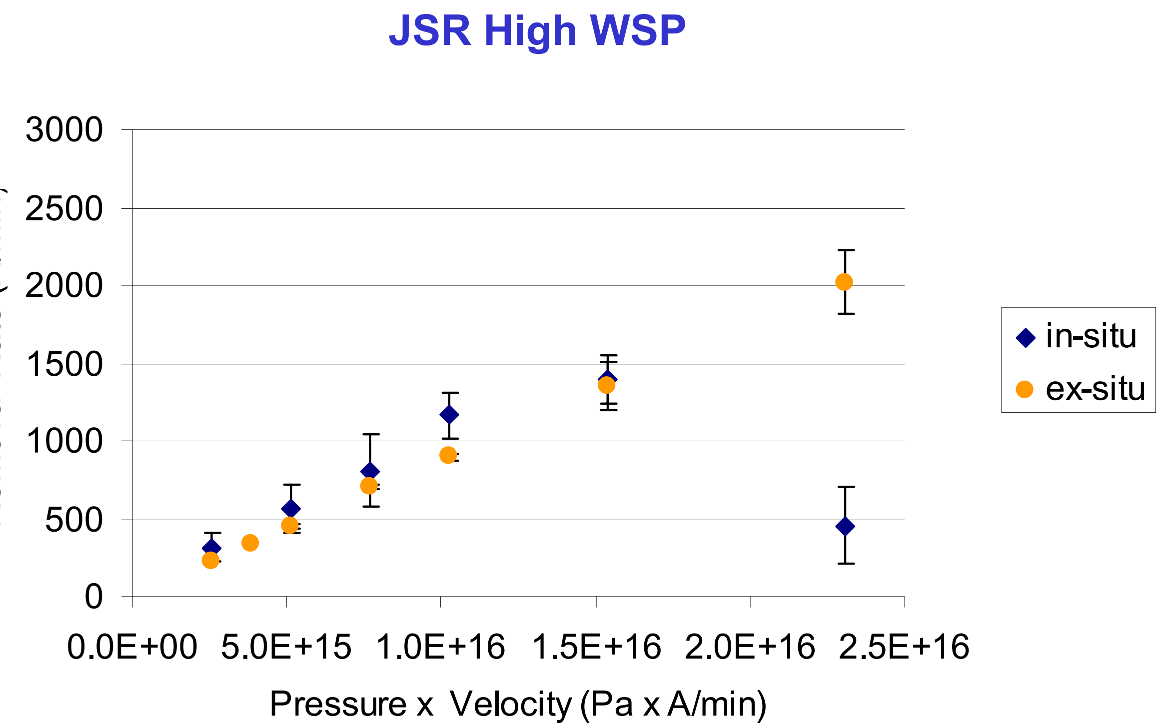


- Removal Rate
  - The Standard WSP pad demonstrates a linear relationship with P x V
  - There was a decrease in RR at the highest P x V setting (6 PSI x 0.93 m/s) during in-situ conditioning
  - Ex-situ conditioning resolves the above anomalous behavior

JSR High WSP Pad

- Lubrication Region
  - Grooved pads exhibit boundary lubrication for the entire range of Sommerfeld Numbers tested

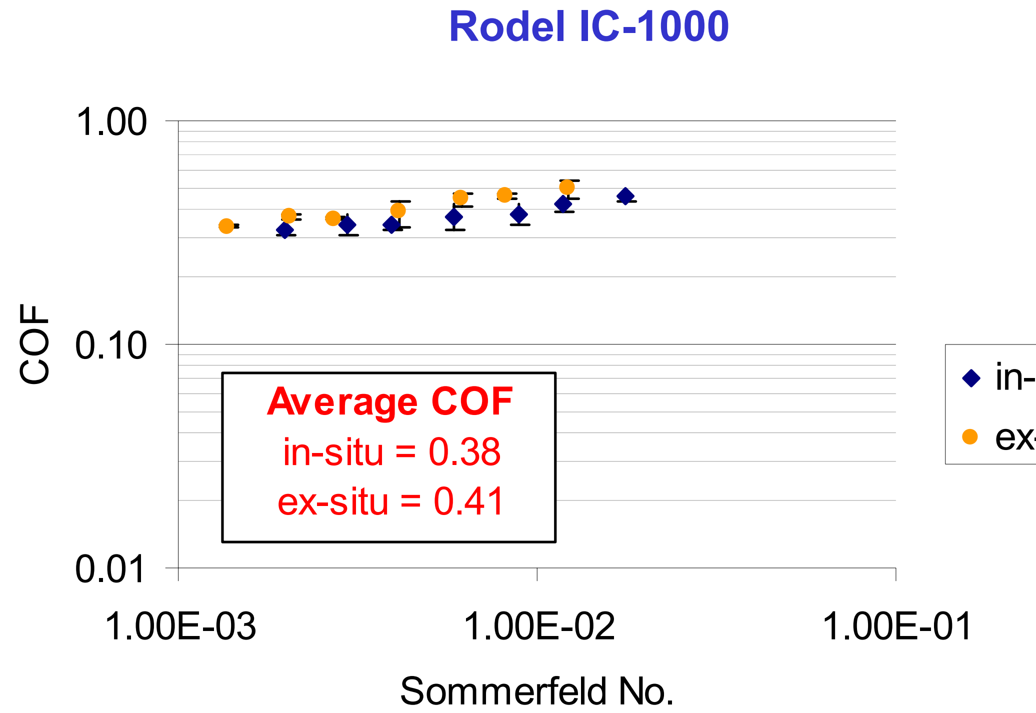


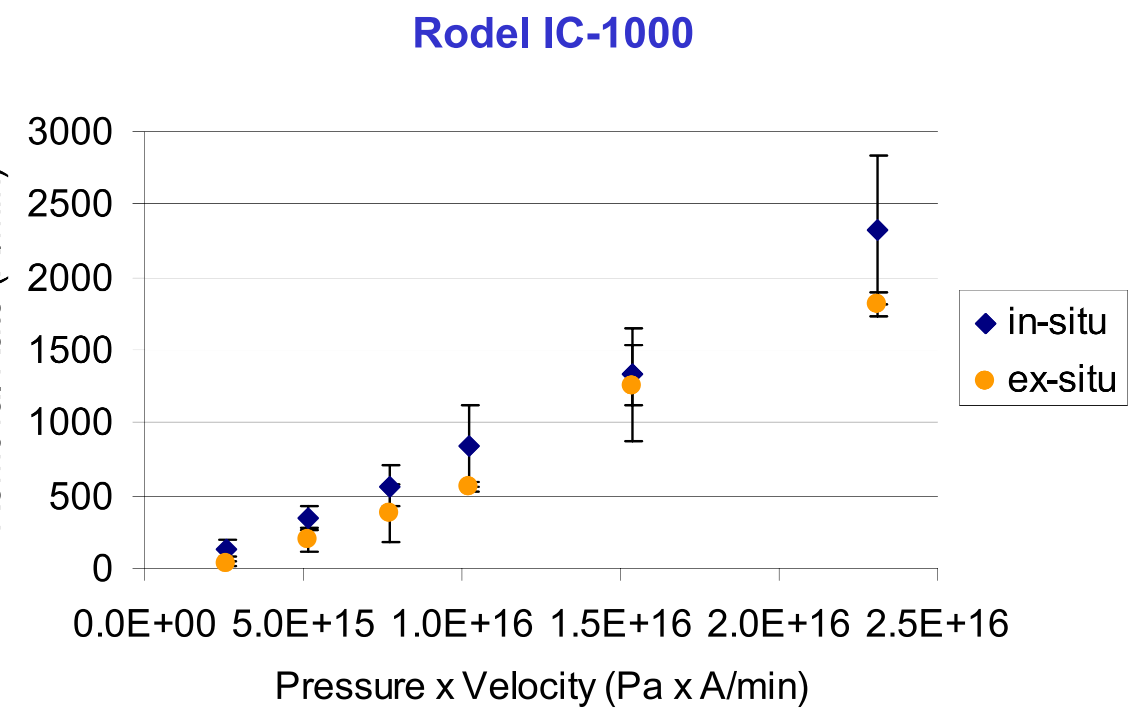


- Removal Rate
  - The Standard WSP pad demonstrates a linear relationship with P x V
  - There was a decrease in RR at the highest P x V setting (6 PSI x 0.93 m/s) during in-situ conditioning
  - Ex-situ conditioning resolves the above anomalous behavior

Rodel IC-1000

- Lubrication Region
  - Grooved pads exhibit boundary lubrication for the entire range of Sommerfeld Numbers tested
  - Rodel IC-1000 has a lower COF than the JSR Standard WSP

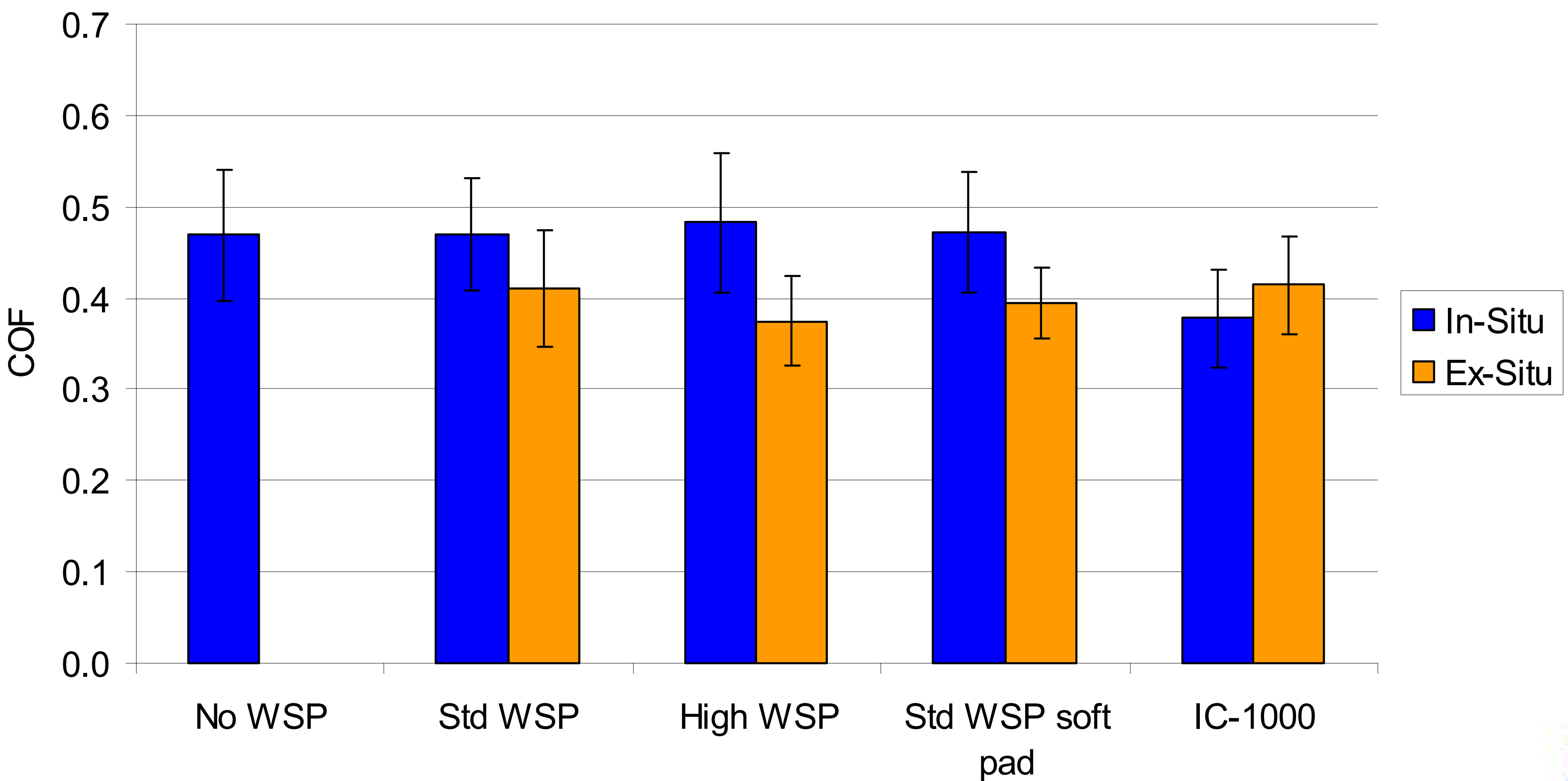




- Removal Rate
  - The Rodel IC-1000 pad demonstrates a linear relationship with P x V
  - There was no decrease in RR at the highest P x V setting (6 PSI x 0.93 m/s) during in-situ conditioning

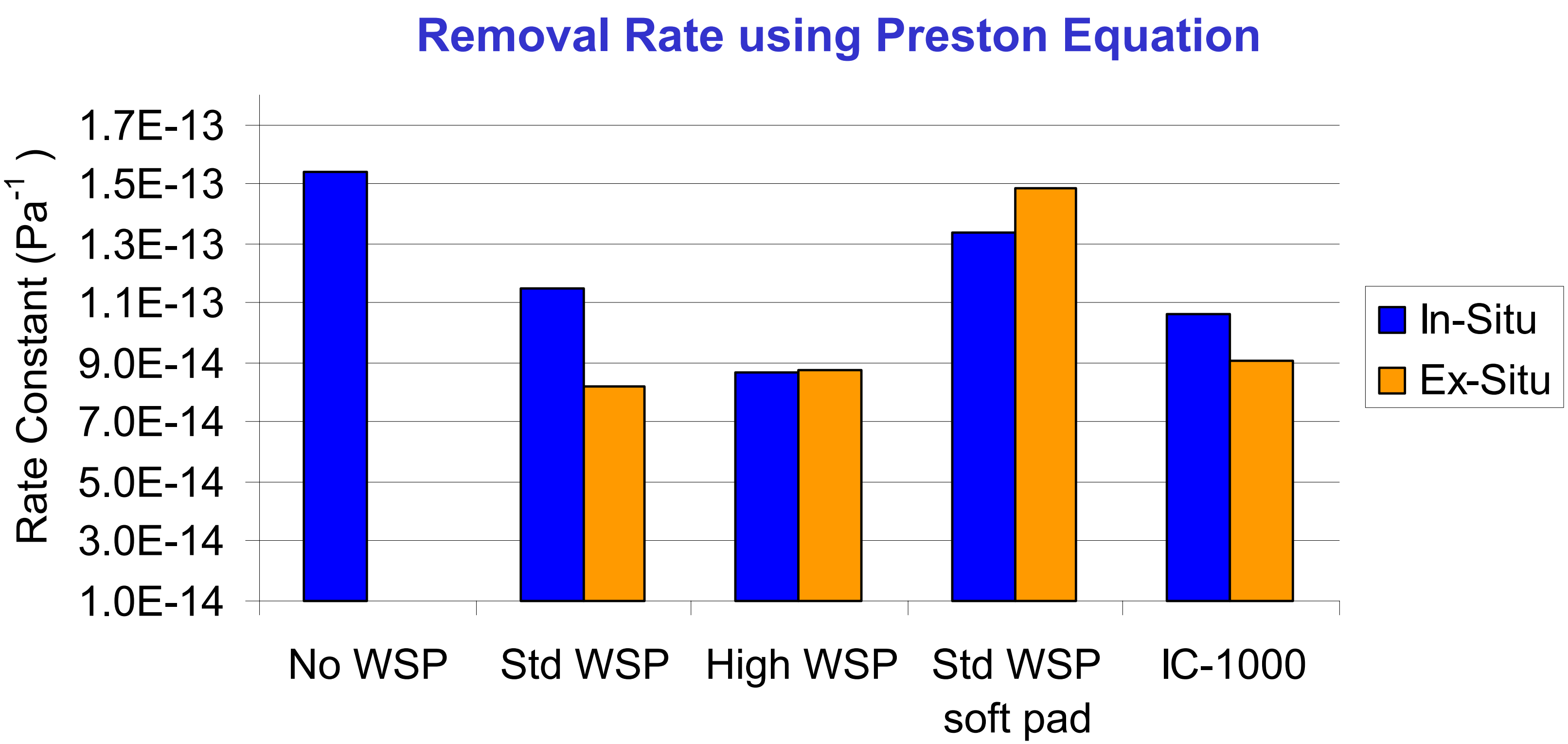
COF Comparison of Grooved Pads

- **COF varies as a function of pad conditioning**
  - **Ex-situ conditioning shows a decrease in COF with the Standard and High WSP pads compared to in-situ conditioning**

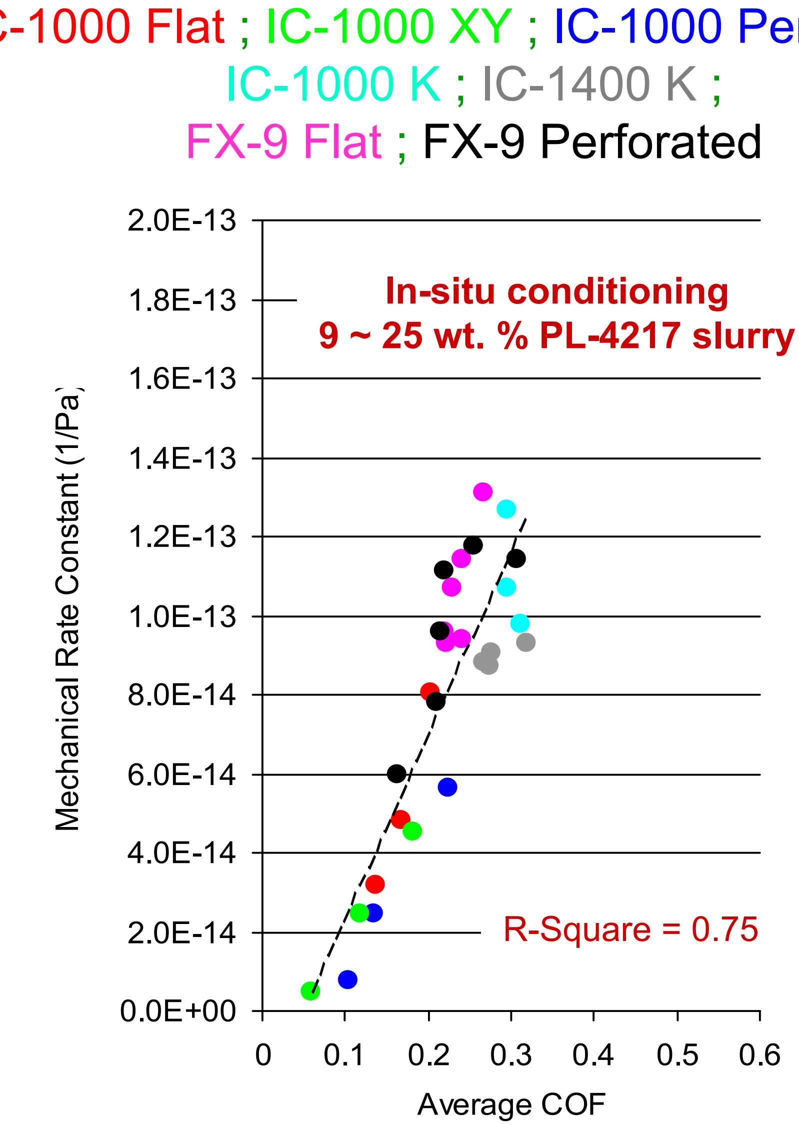


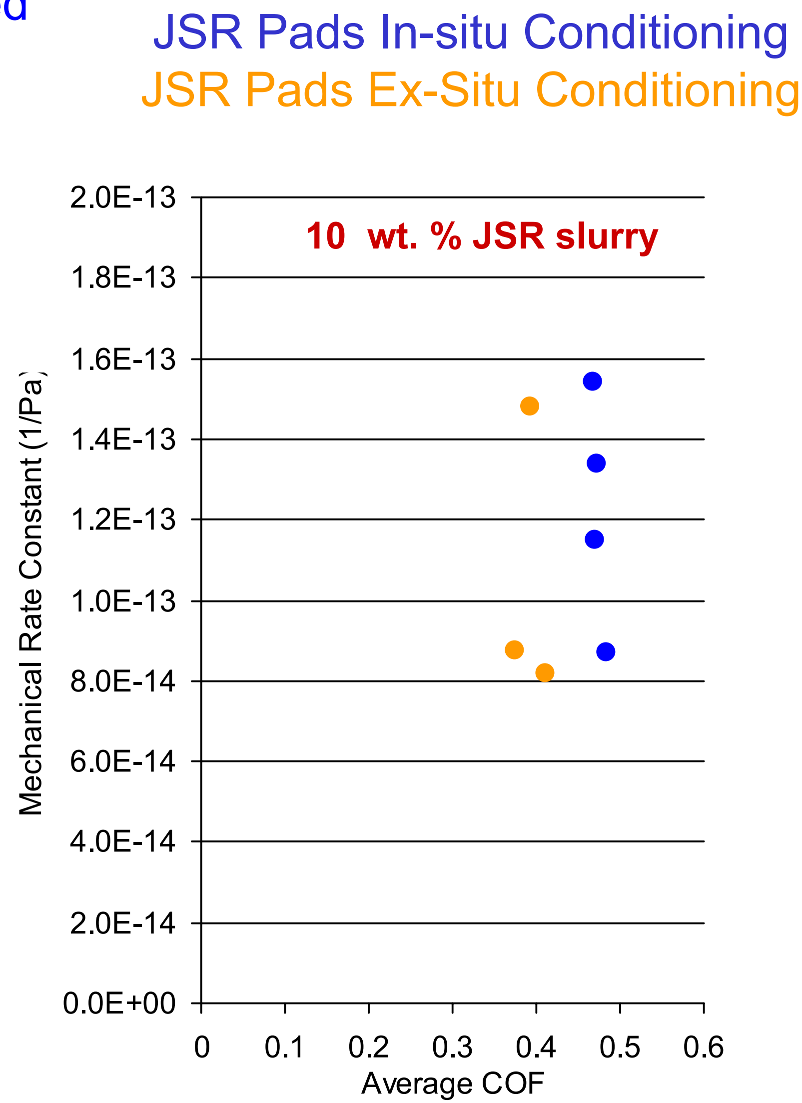
Removal Rate Comparison of Grooved Pads

- **Ex-Situ** conditioning shows that rate constant **increases** with higher WSP content compared to the standard amount
- **In-Situ** conditioning shows that rate constant **deceases** with higher WSP content compared to the standard amount
- JSR no WSP pad shows the highest rate constant for in-situ conditioning
- JSR low matrix hardness pad shows the highest rate constant for ex-situ conditioning



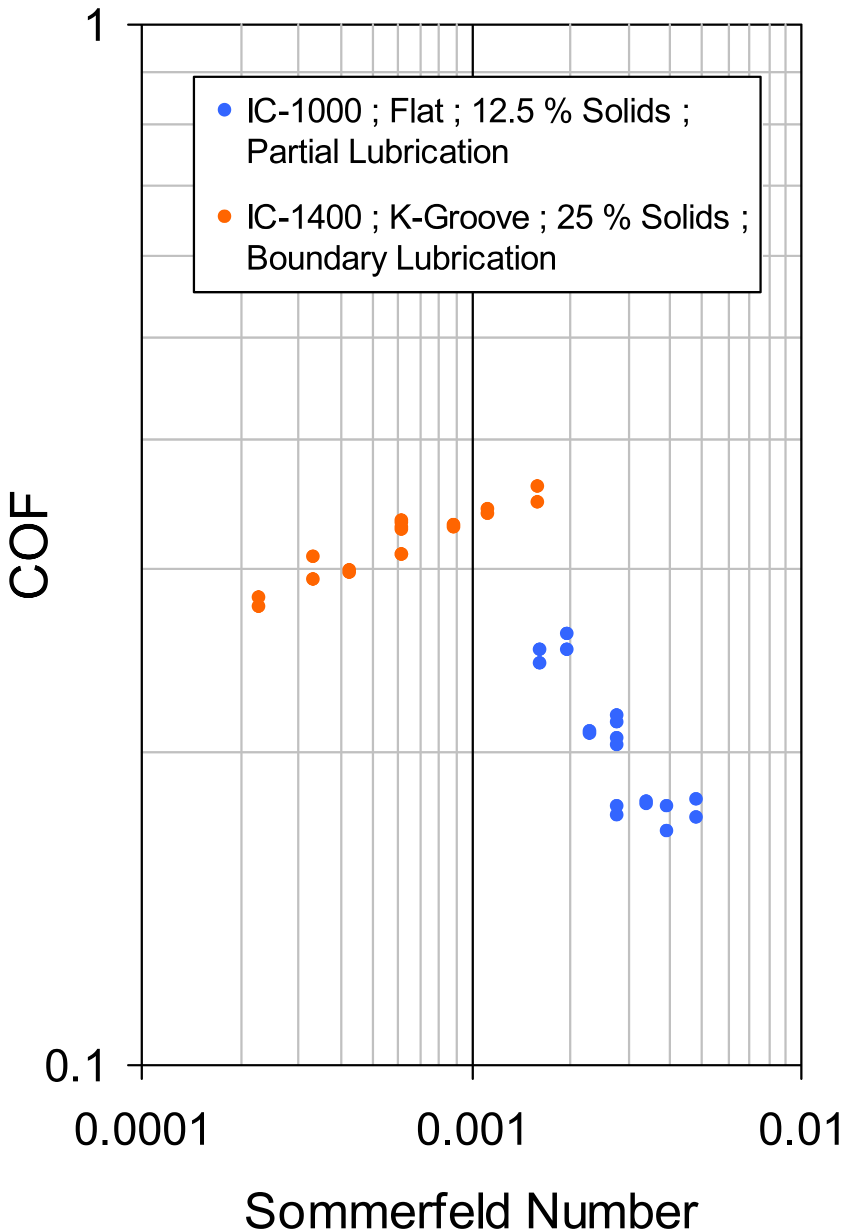
Correlating ILD RR to Average COF

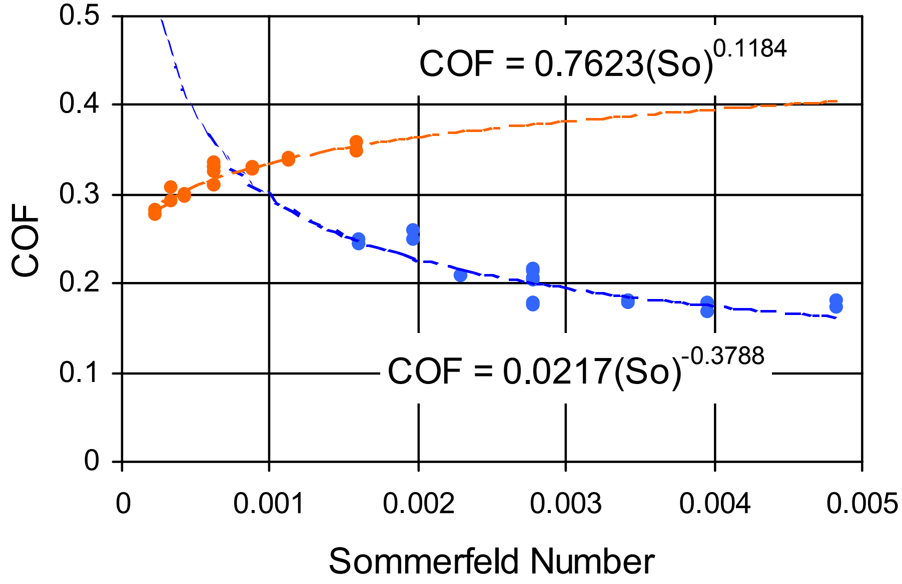




$$\text{Removal Rate} = (k_m k_c)(P)(V)$$

Characterizing & Quantifying Lubrication Regimes





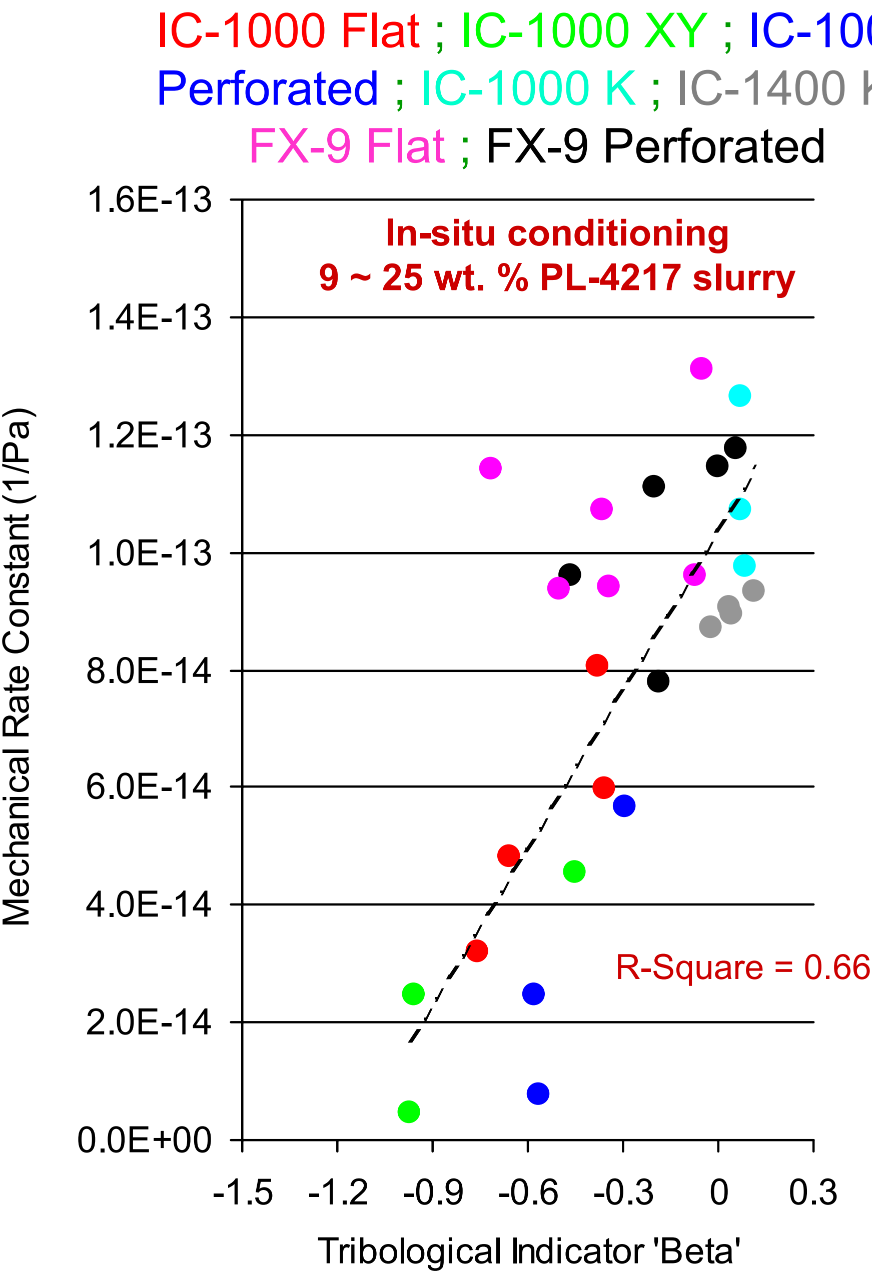
$$COF_{avg} = \frac{\sum_{\text{all values of 'So'}} (COF)}{n}$$

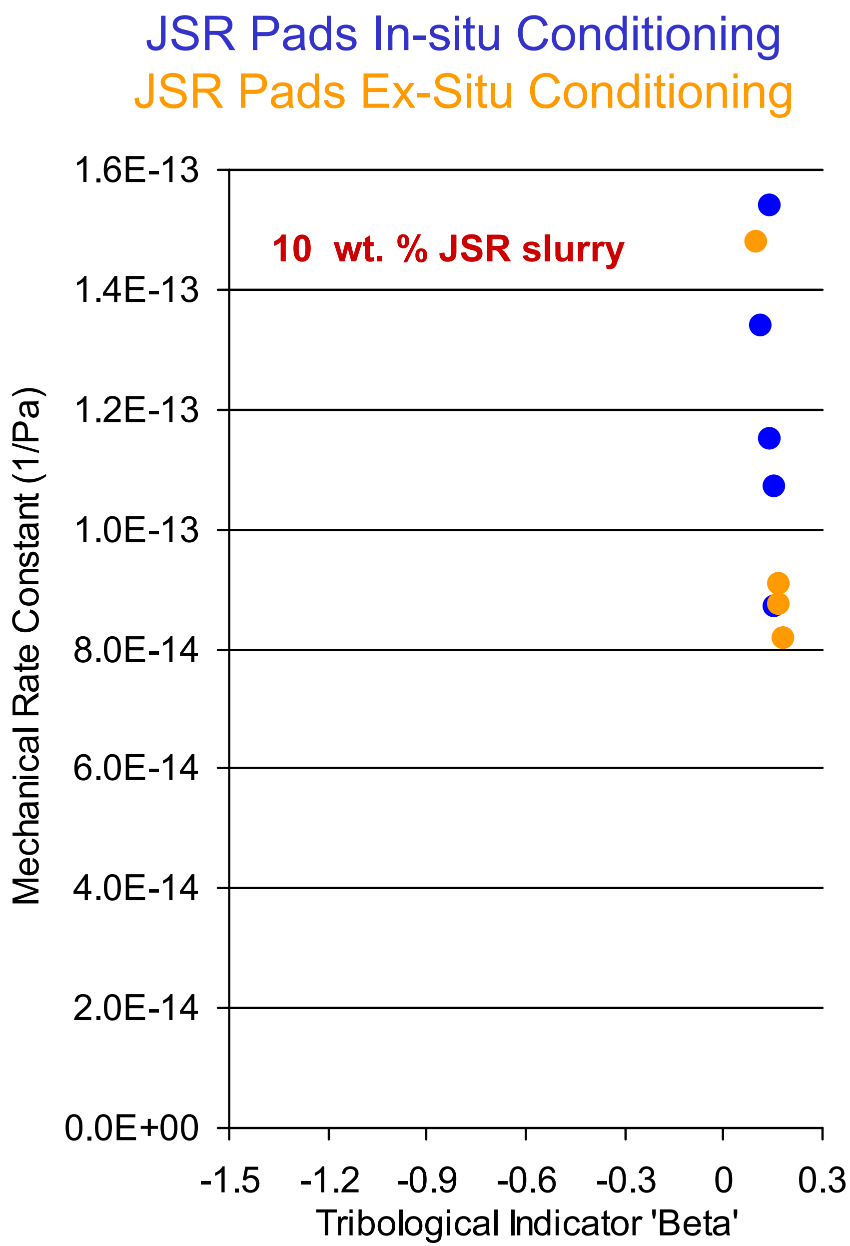
$$COF = A \times (So)^{\beta}$$

$\beta \geq 0$ ... *Boundary Lubrication*

$\beta < 0$ ... *Extent of Partial Lubrication*

Correlating Tribological Indicator to Rate Constant

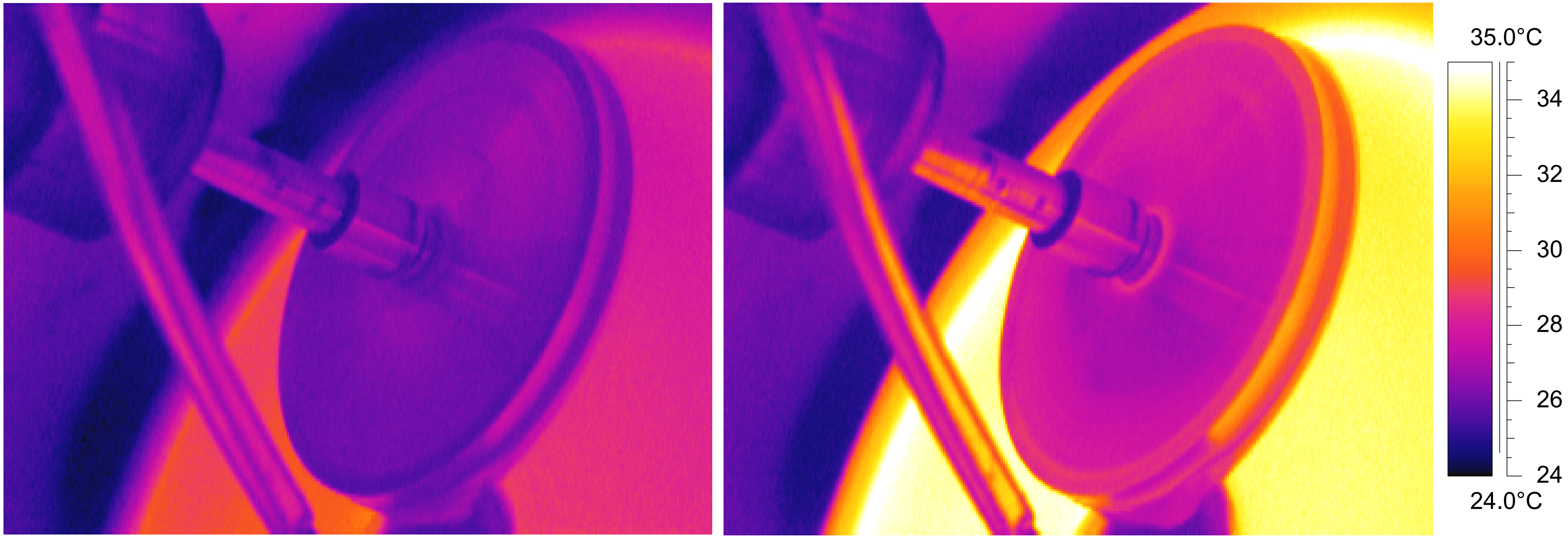




Infrared Temperature Measurement During CMP

- IR camera (on loan from MIT) can measure temperatures of the pad and slurry during the CMP process
  - Bow Wave: Slurry build up at the leading edge of the wafer
  - Bow Wave Temperature: Slurry temperature before it goes under the wafer

Polish Conditions: 6PSI, 0.93m/s



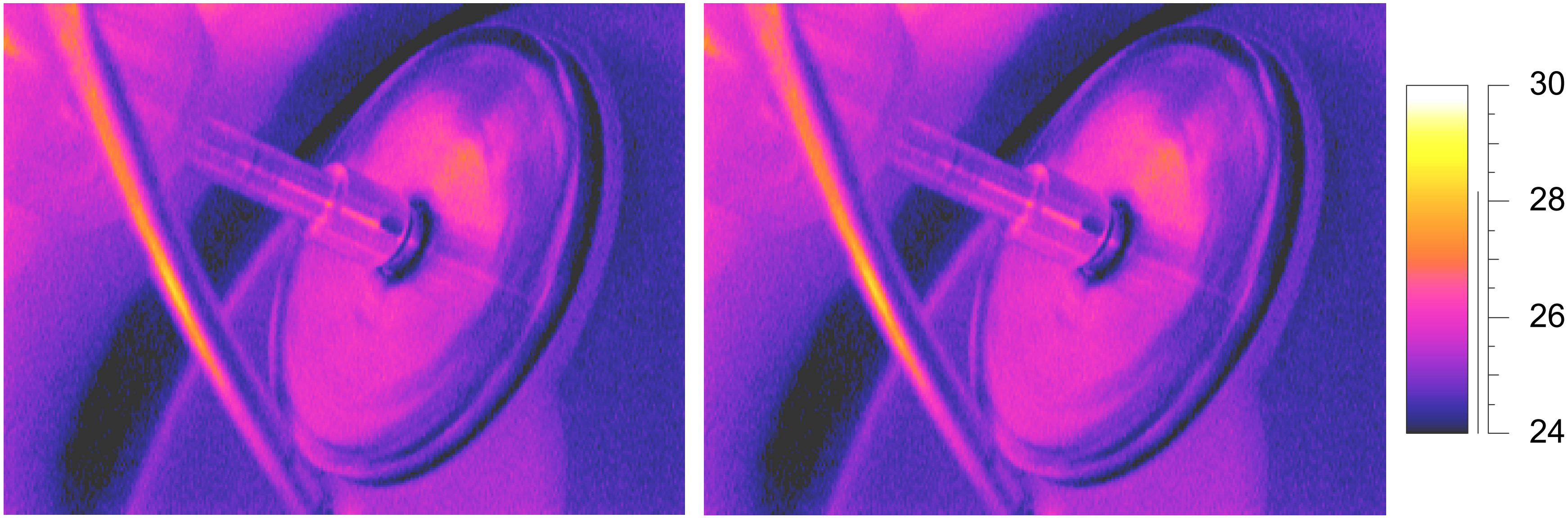
Polish Time = 3 seconds

Polish Time = 60 seconds

- Temperature increases at the bow wave over a 1 minute polish
- Temperature increases at the pad over a 1 minute polish

Infrared Temperature Measurement During CMP

Polish Conditions: 2PSI, 0.31m/s

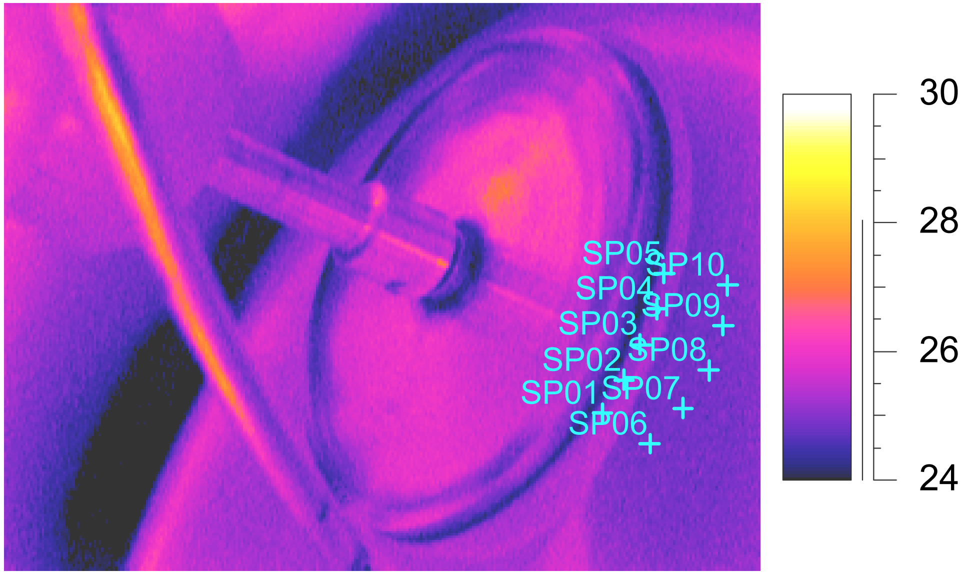


Polish Time = 3 seconds

Polish Time = 60 seconds

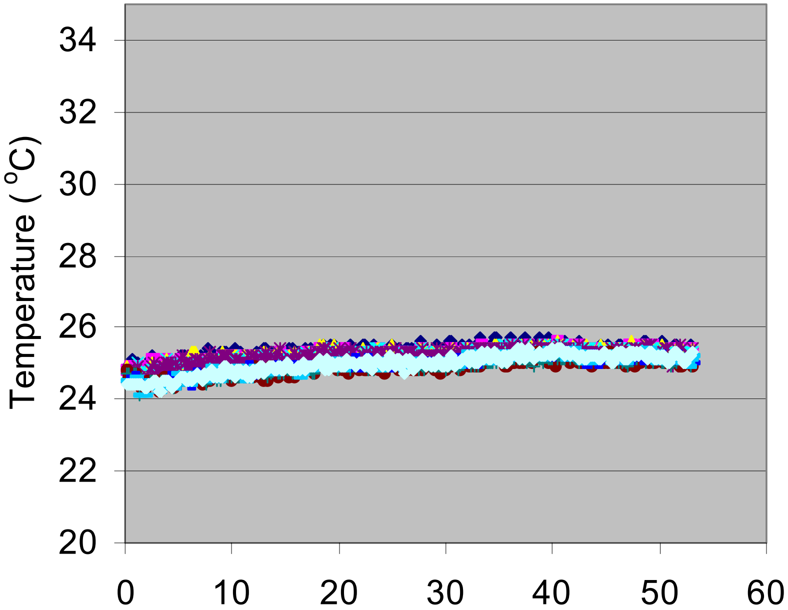
- Temperature does not increase at the bow wave over a 1 minute polish
- Temperature does not increase at the pad over a 1 minute polish

Infrared Temperature Analysis

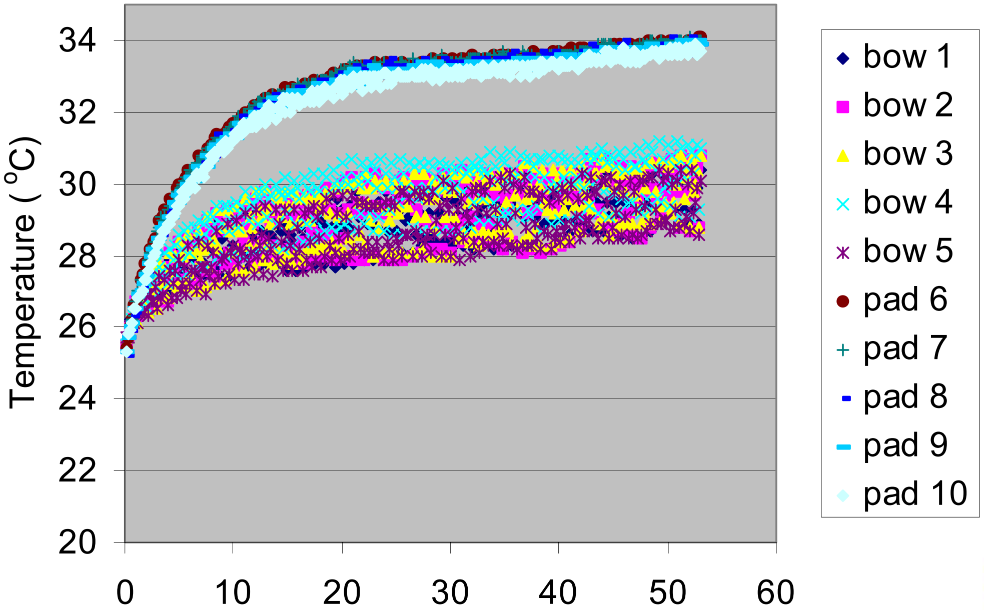


- Temperature analysis is performed over the indicated spots
- A “real time” temperature measurement is recorded from the moment the wafer touches the pad

2 PSI, 0.31 m/s

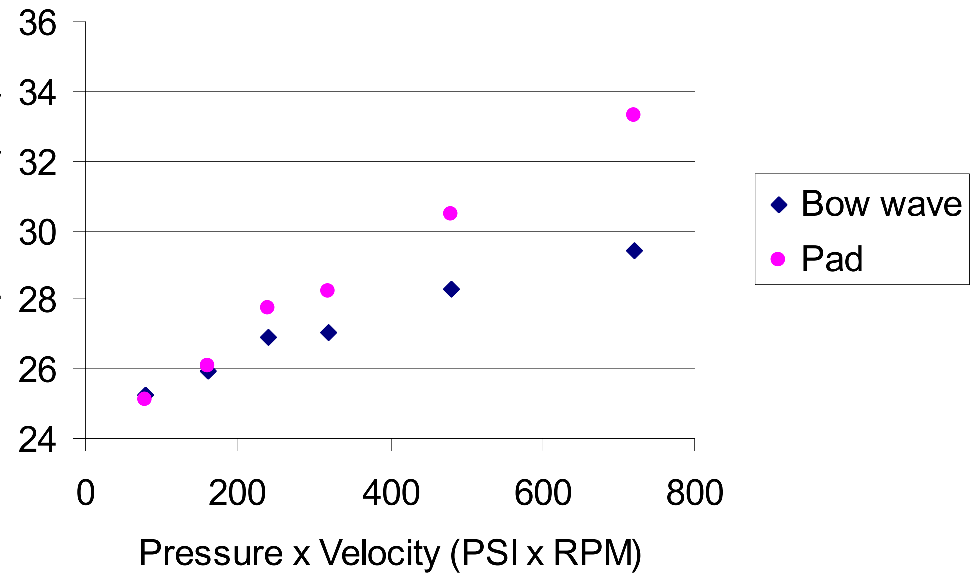


6 PSI, 0.93 m/s

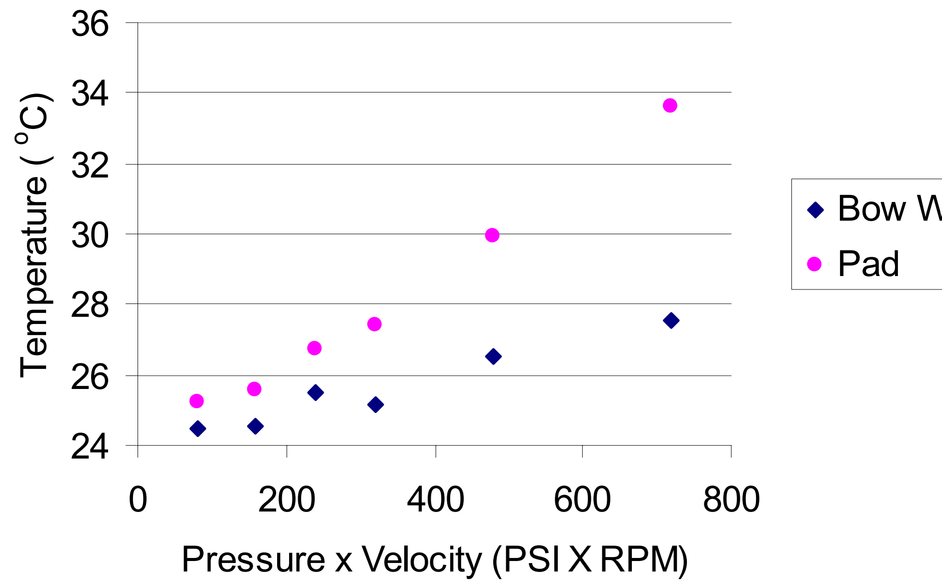


IR Temperature Results Ex-Situ Pad Conditioning

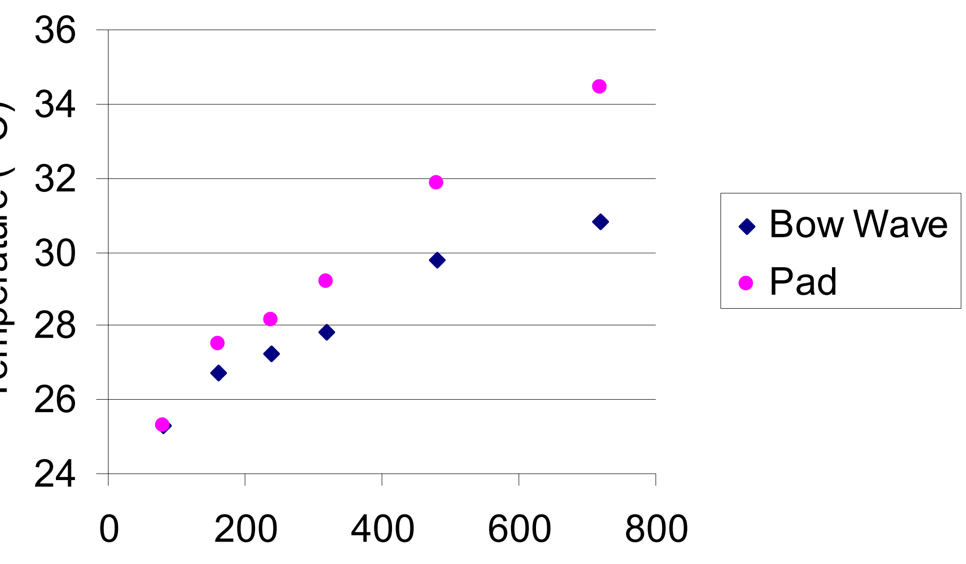
Standard WSP



High WSP



IC-1000



- Temperature increases with P x V for both the bow wave and the pad
- As P x V increases, the temperature difference between the pad and the bow wave increases
- IC-1000 bow wave temperature is 1.2 °C higher than the Std WSP pad
- IC-1000 pad temperature is 1.5 °C higher than the Std WSP pad

Conclusions & Observations

- Tribology - JSR Grooved Pads
  - All grooved pads remained in the boundary lubrication region for the entire range of Sommerfeld Numbers tested
- Pad conditioning on pads with WSP
  - JSR pads are unique due to presence of WSPs which cause self regeneration of the pad surface
  - WSP causes anomalous behavior at high P x V settings in conjunction with in-situ conditioning by causing the RR to decrease at the highest setting (6PSI & 0.93m/s)
  - It is not necessary to condition the surface of the pad while polishing
    - In-situ conditioning is too harsh on the surface and may cause particles to dislodge rather than dissolve
- Relationship to previously obtained universal COF & “beta” curves
  - As a first approximation, frictional and tribological characteristics of JSR pads seem to follow trends observed with other pads and slurries
  - Differences are speculated to be due to varying amounts of WSP
- Thermal analysis
  - The temperature increases at the bow wave with P x V
  - The temperature increases on the pad surface with P x V
  - Although bow wave and pad temperature differences are small (1-2 ^{o}C increase) between each pad type, it may be significant since the activation energies are yet to be determined

Future Plans

- Water Soluble Particles
  - Determine dissolution rates of the WSP
  - Temperature effects on the WSP
  - pH effects on WSP

- Thermal Analysis
  - Analysis of temperature trends
  - Correlation to dissolution rates of WSP and heats of mixing

- Thermal and Dynamic pad properties
  - Pad softening occurring at standard CMP operating temperatures
  - Pad toughening
  - Cross linking and extent of free volume of pad composition
  - Glass transition temperatures

- Wafer Pressure Analysis
  - Localized high pressure points
  - WSP content effects on pressure

- Collaboration with Arizona State University to model removal rate in terms of pad surface and mechanical features

Acknowledgements

- Duane Boning
- Gary Chandler
- Lorenzo Lujan

- NSF/SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing
- Tufts University (collaboration & technology exchange)

- JSR Corp
- Fujimi Incorporated (slurry donation)
- Freudenberg Nonwovens (pad donation)
- Rodel (pad donation)