Thermal and Mechanical Properties of CMP Pads Containing Embedded Water Soluble Particles

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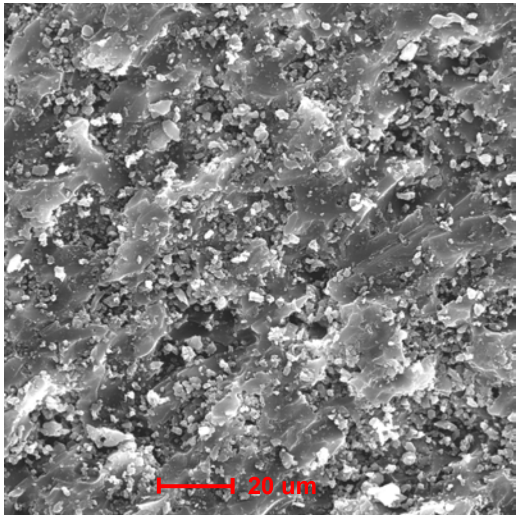
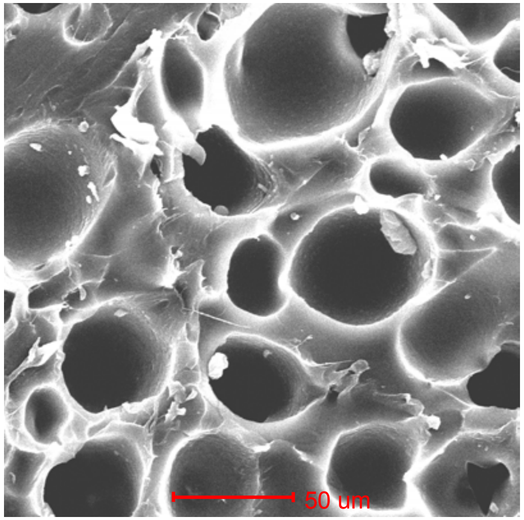
Motivation / Outline

- To characterize a novel pad design that incorporates water soluble particles (WSP) embedded in the pad composition as it relates to:
  - Tribology
  - Removal Rate
  - Thermal Analysis
  - Pad Physical Properties
  - Pad Conditioning

- To perform a comparative analysis of concentric grooved pads including:
  - JSR No WSP
  - JSR Standard WSP
  - JSR High WSP
  - JSR Standard WSP - Soft
  - Rodel IC-1000



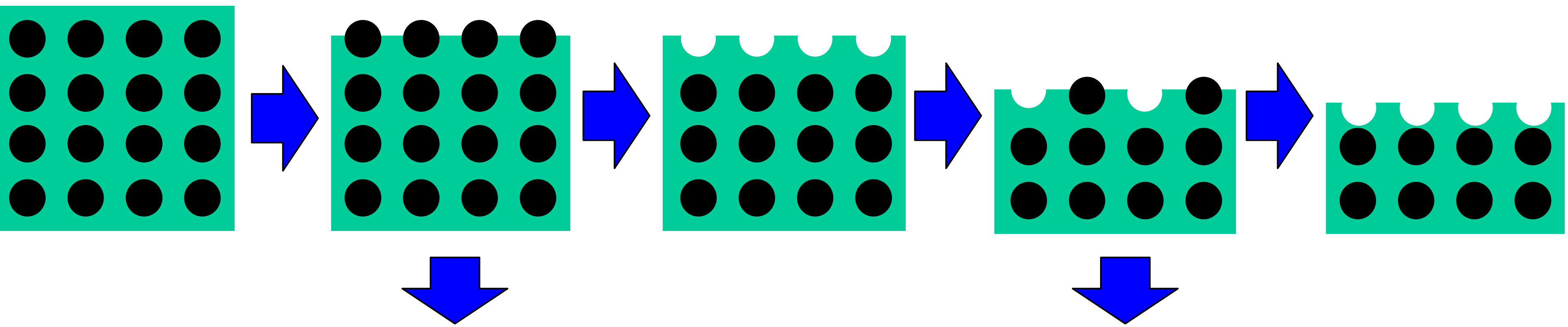
JSR Pad with WSP (new)
Controlled Porosity Pad

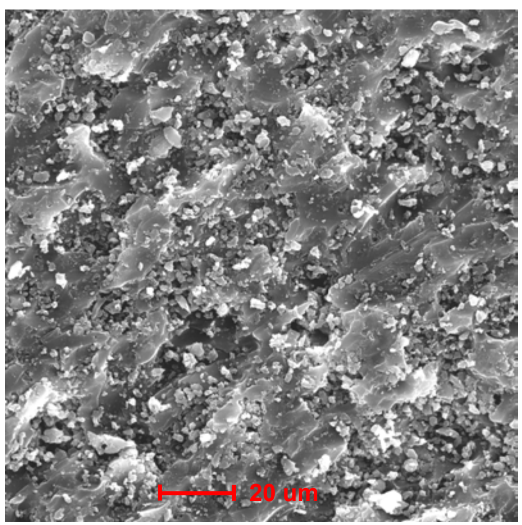


Rodel IC-1000 (new)

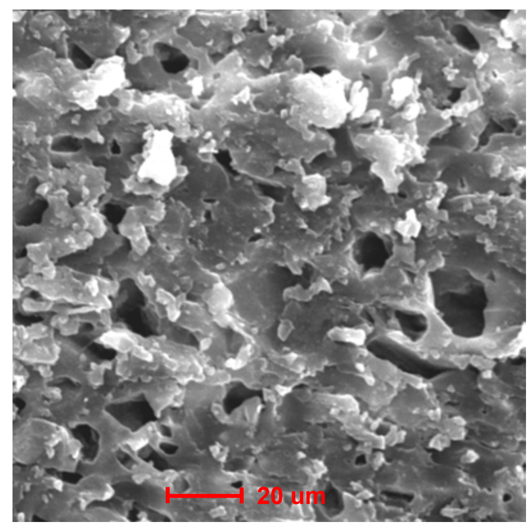
Process of Surface Self Regeneration via WSP

JSR Self-Regenerating Pads with Controlled Porosity





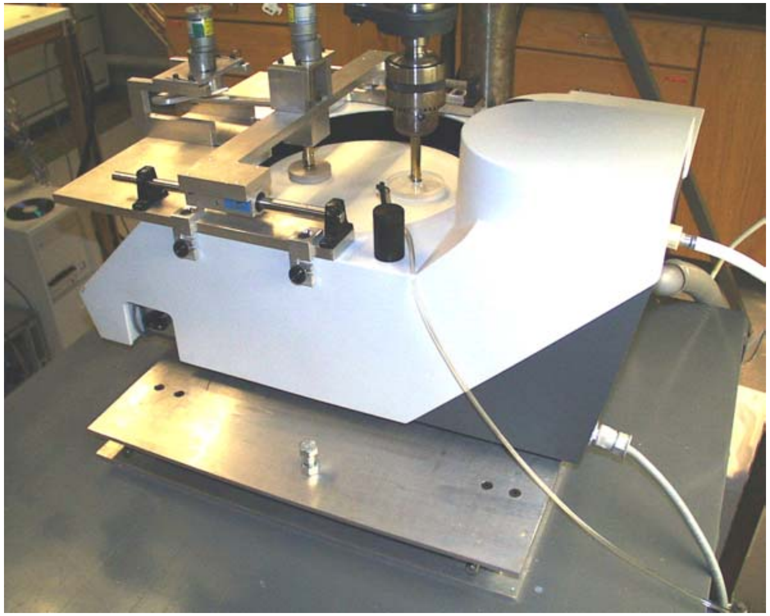
JSR Pad with Std WSP (new)

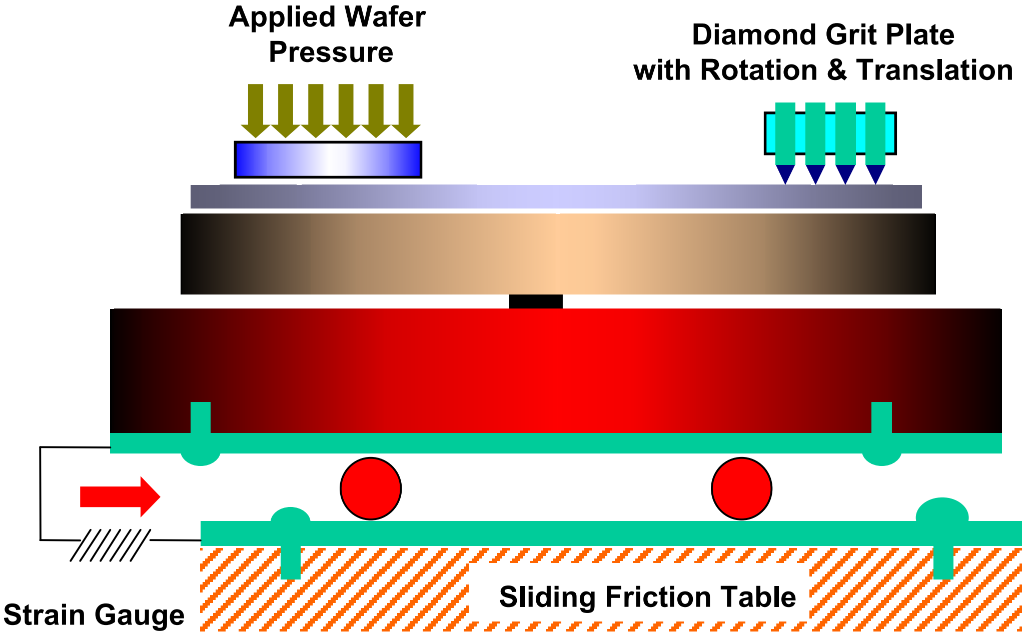


JSR Pad with Std WSP (used)

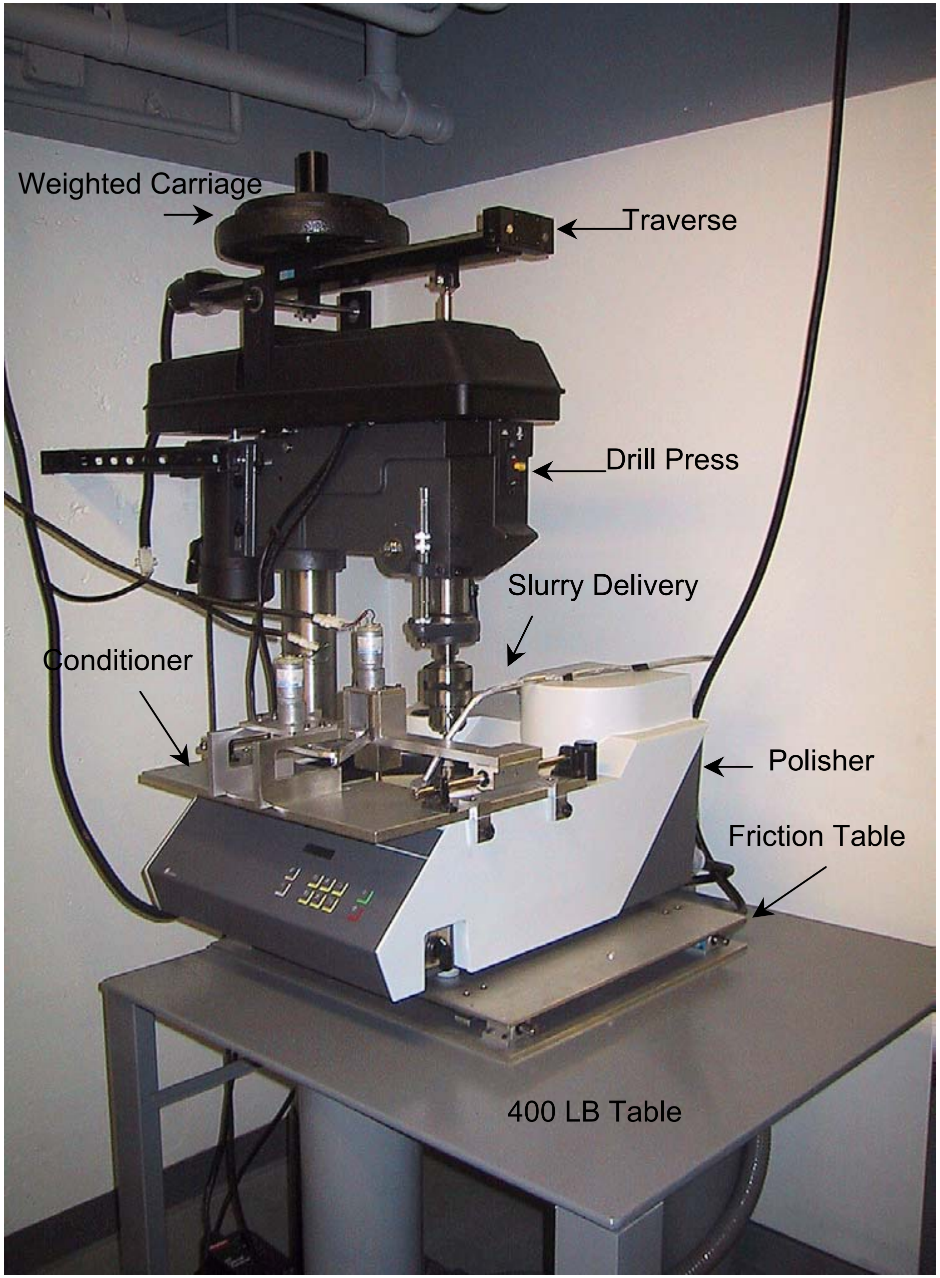
Apparatus

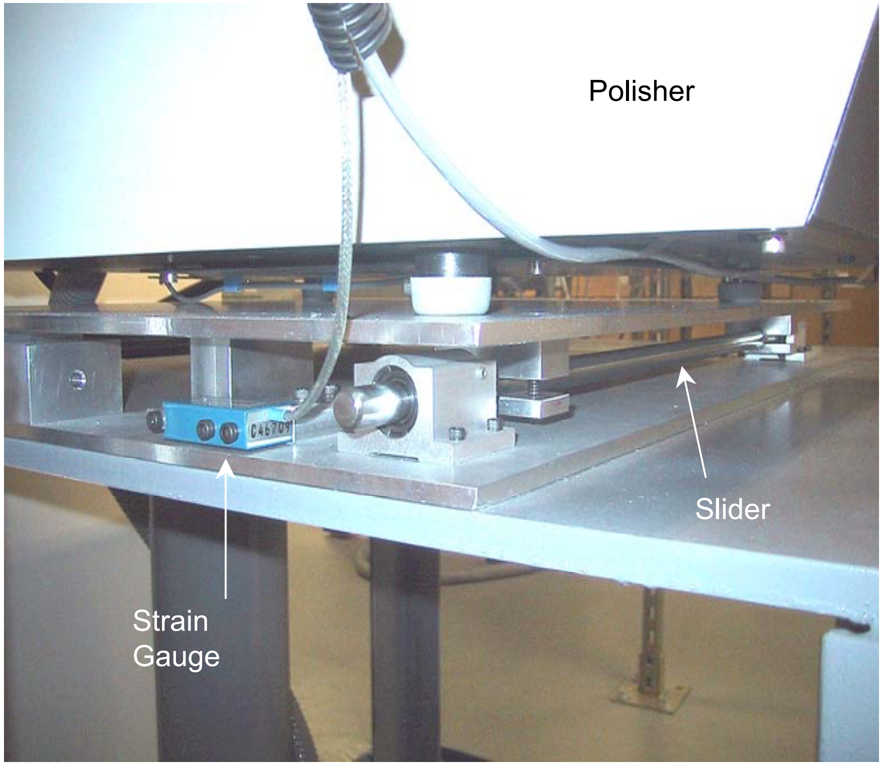
Parameter	Scaling Factor	Speedfam-IPEC 472	Rotopol-35
Down Pressure	1	4 psi	4 psi
Platen Speed	Reynolds Number	Relative pad-wafer velocity of 0.5 m per second (30 rpm)	Relative pad-wafer velocity of 0.5 m per second (55 rpm)
Platen Diameter / Wafer Diameter	D_{platen} / D_{wafer}	51 cm / 15 cm	31 cm / **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

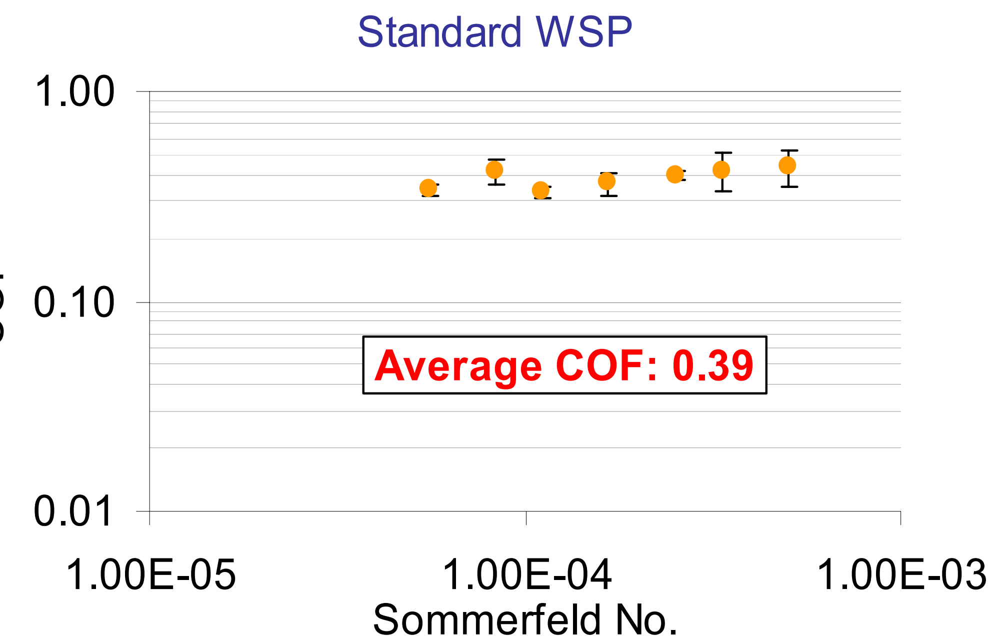


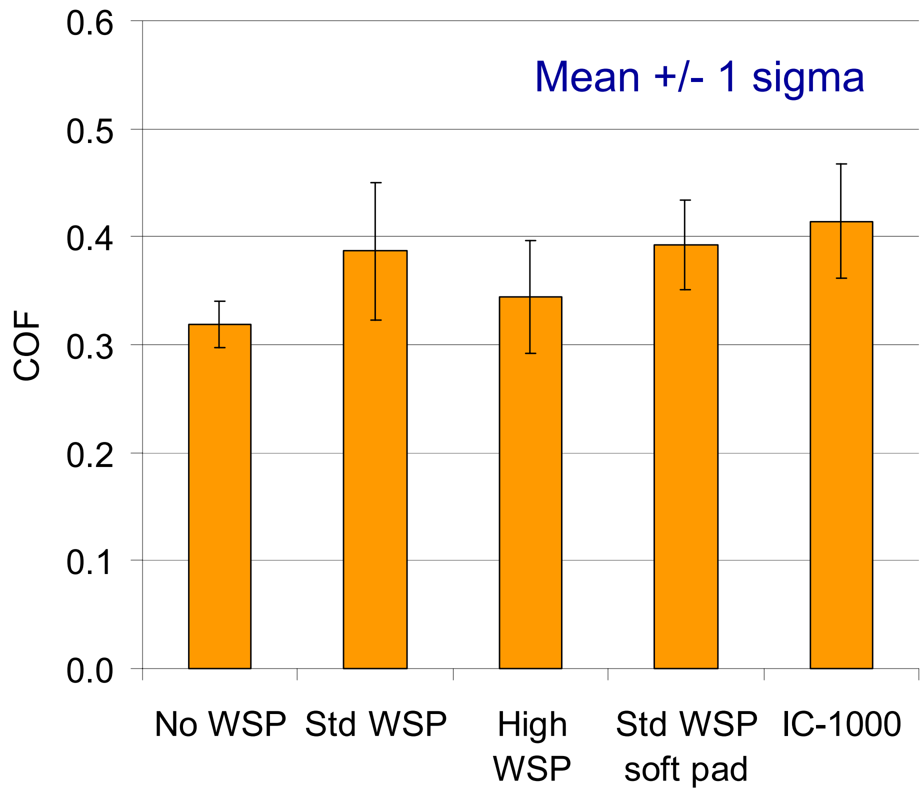


$$COF = \frac{F_{Shear}}{F_{Normal}}$$

Tribology

Stribeck-Gumbel Curve

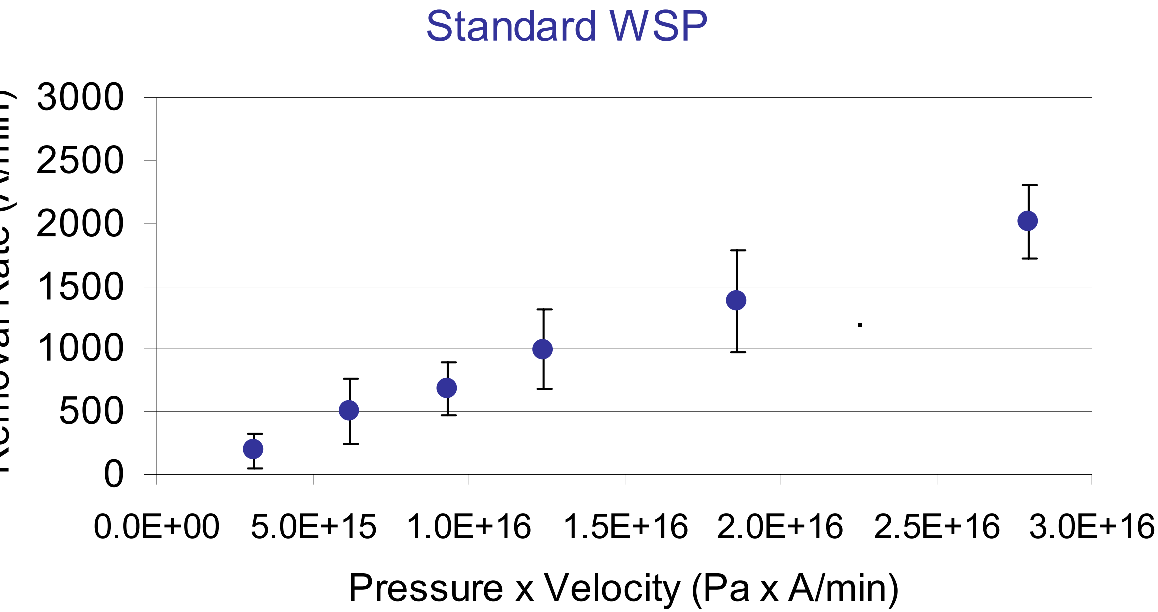




$$So = \frac{(u) \times (\mu)}{(P_{act}) \times (\delta_{eff})}$$

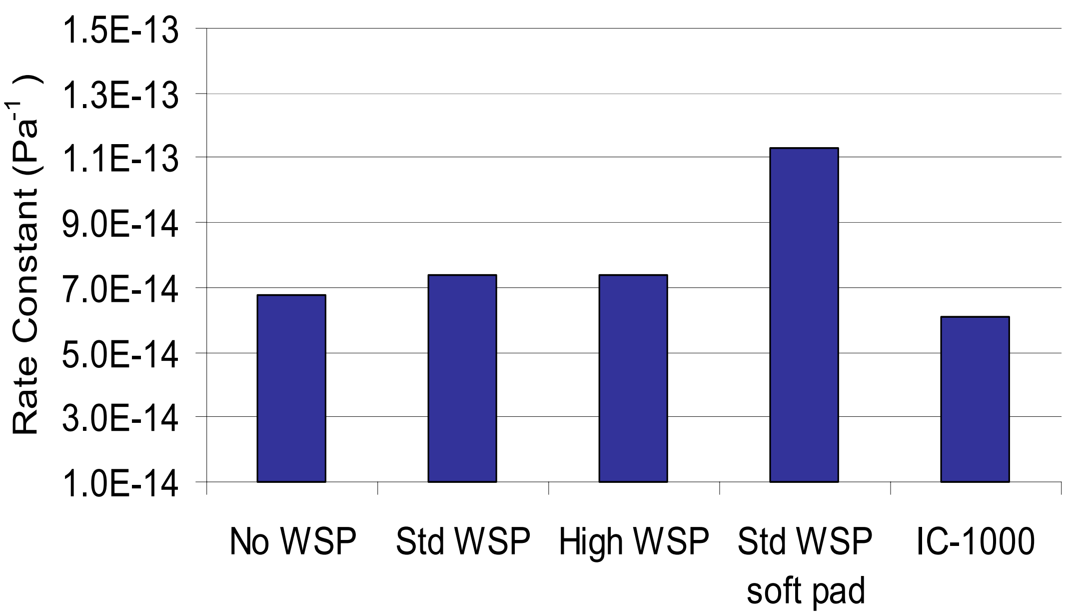
- Lubrication Region
  - Grooved pads exhibit boundary lubrication for the entire range of Sommerfeld Numbers tested

Removal Rate



- Removal Rate
  - All pads demonstrate a linear relationship with P x u
  - The Standard WSP - lower matrix hardness pad has the highest removal rate

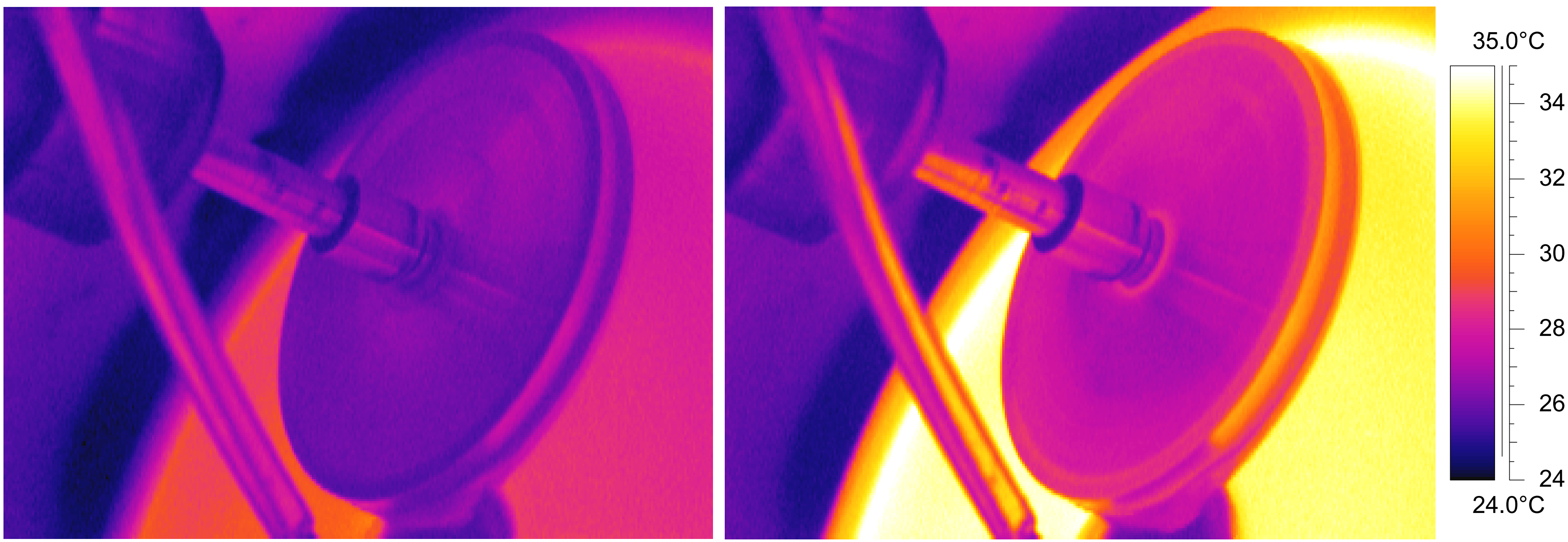
$$RR = k \times P \times u$$



Infrared Temperature Measurement During CMP

- IR camera 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: 6 PSI & 0.93 meters per second



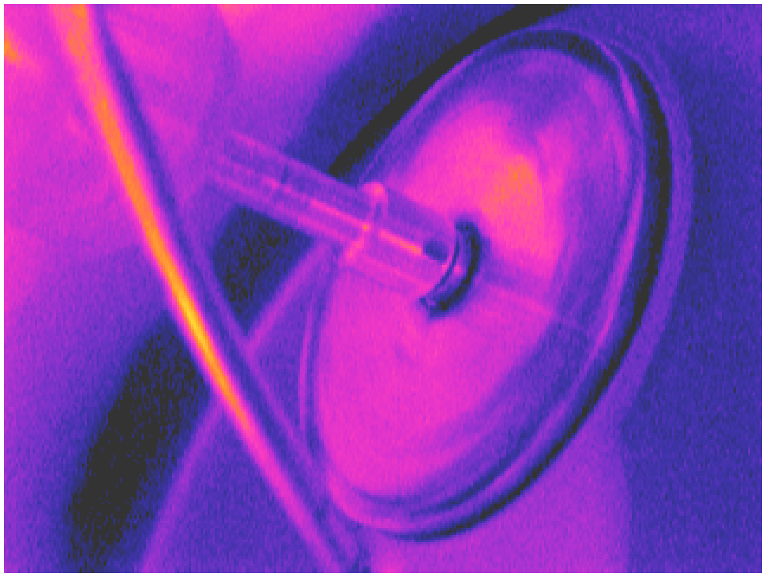
Polish Time = 3 seconds

Polish Time = 60 seconds

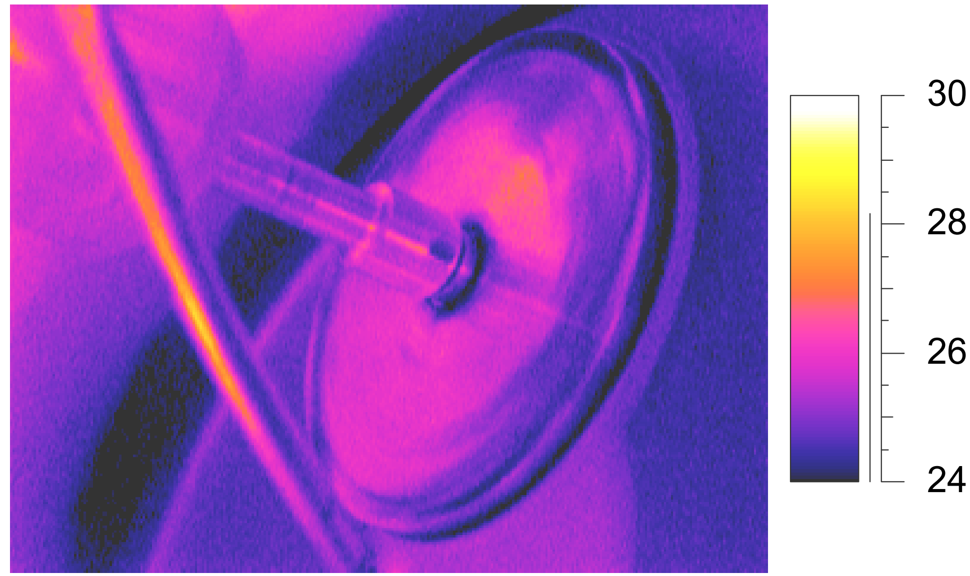
- Temperature increases at the bow wave over a 1-min polish
- Temperature increases on the pad over a 1-min polish

Infrared Temperature Measurement During CMP

Polish Conditions: 2 PSI & 0.31 meters per second



Polish Time = 3 seconds

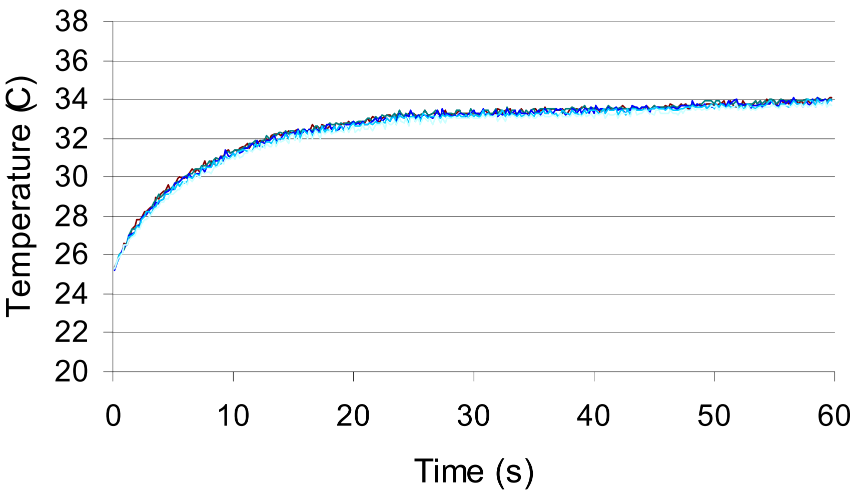


Polish Time = 60 seconds

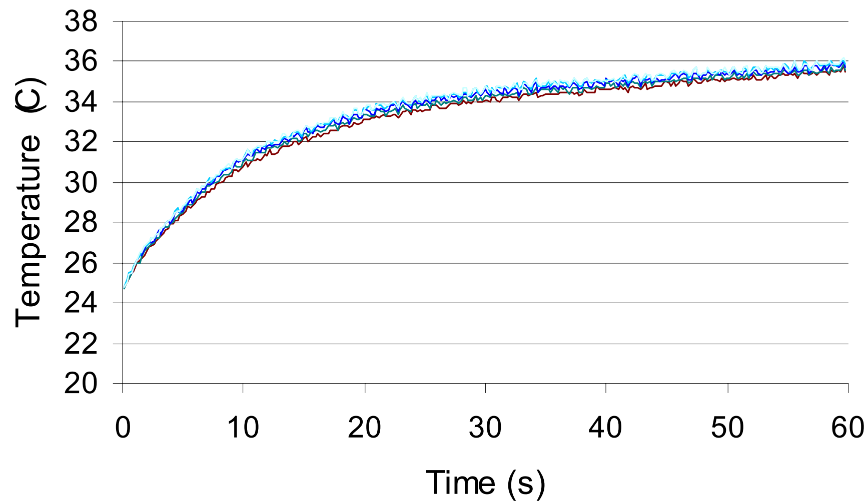
- Temperature does not increase at the bow wave over a 1-min polish
- Temperature does not increase on the pad over a 1-min polish

Temperature Increase of the Pad During CMP

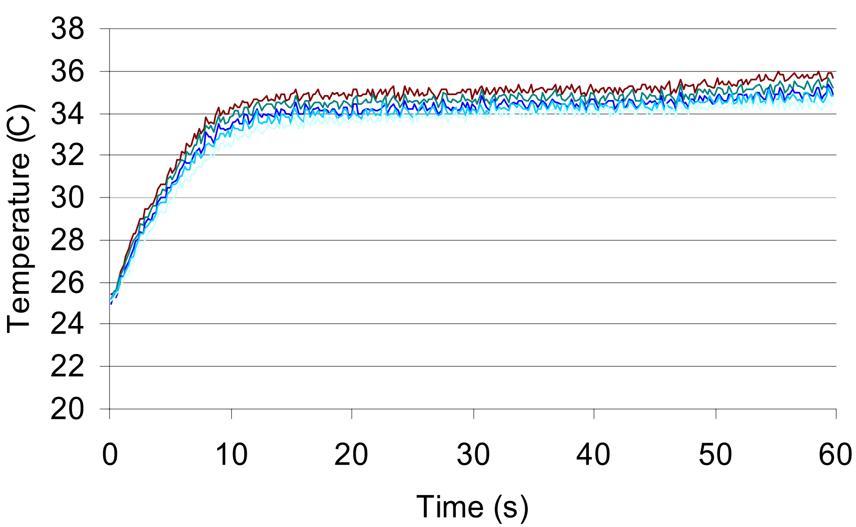
Standard WSP



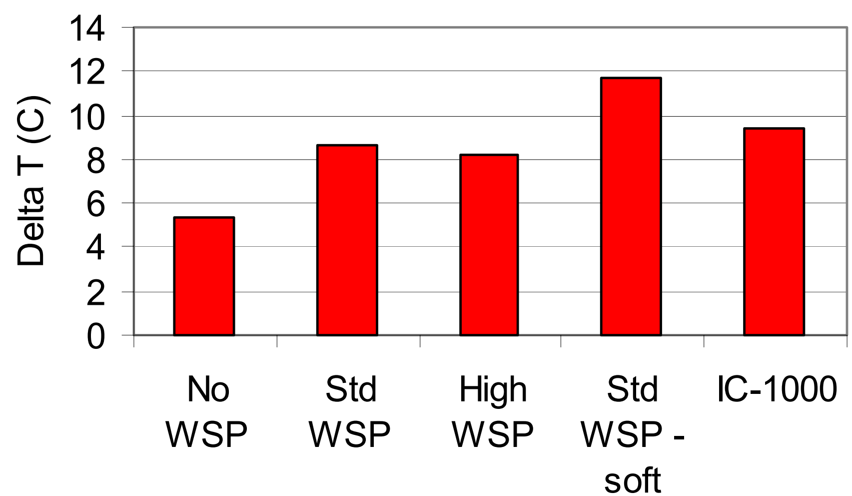
Standard WSP - Soft



IC-1000



Temperature Increase for 1-min Polish

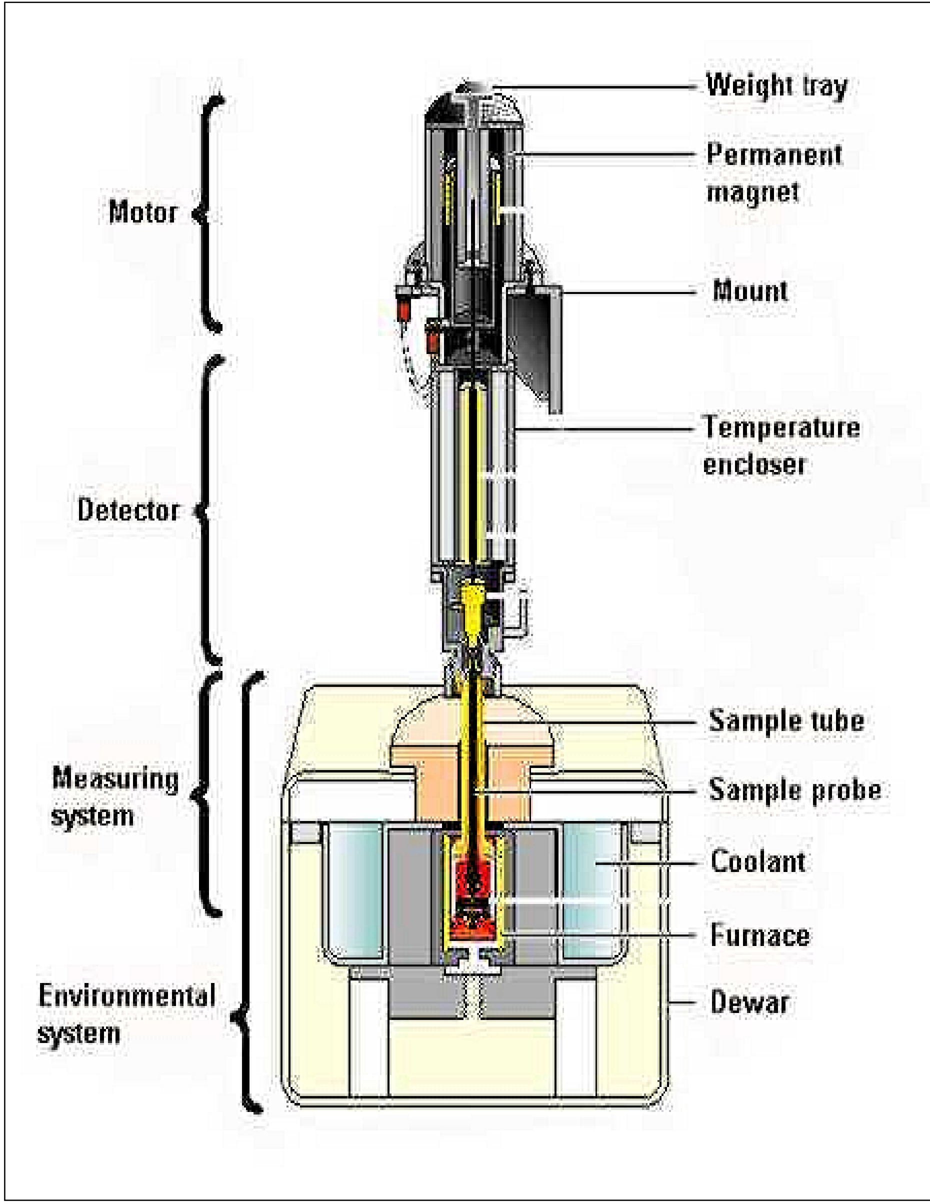


Dynamic Mechanical Analyzer (DMA)

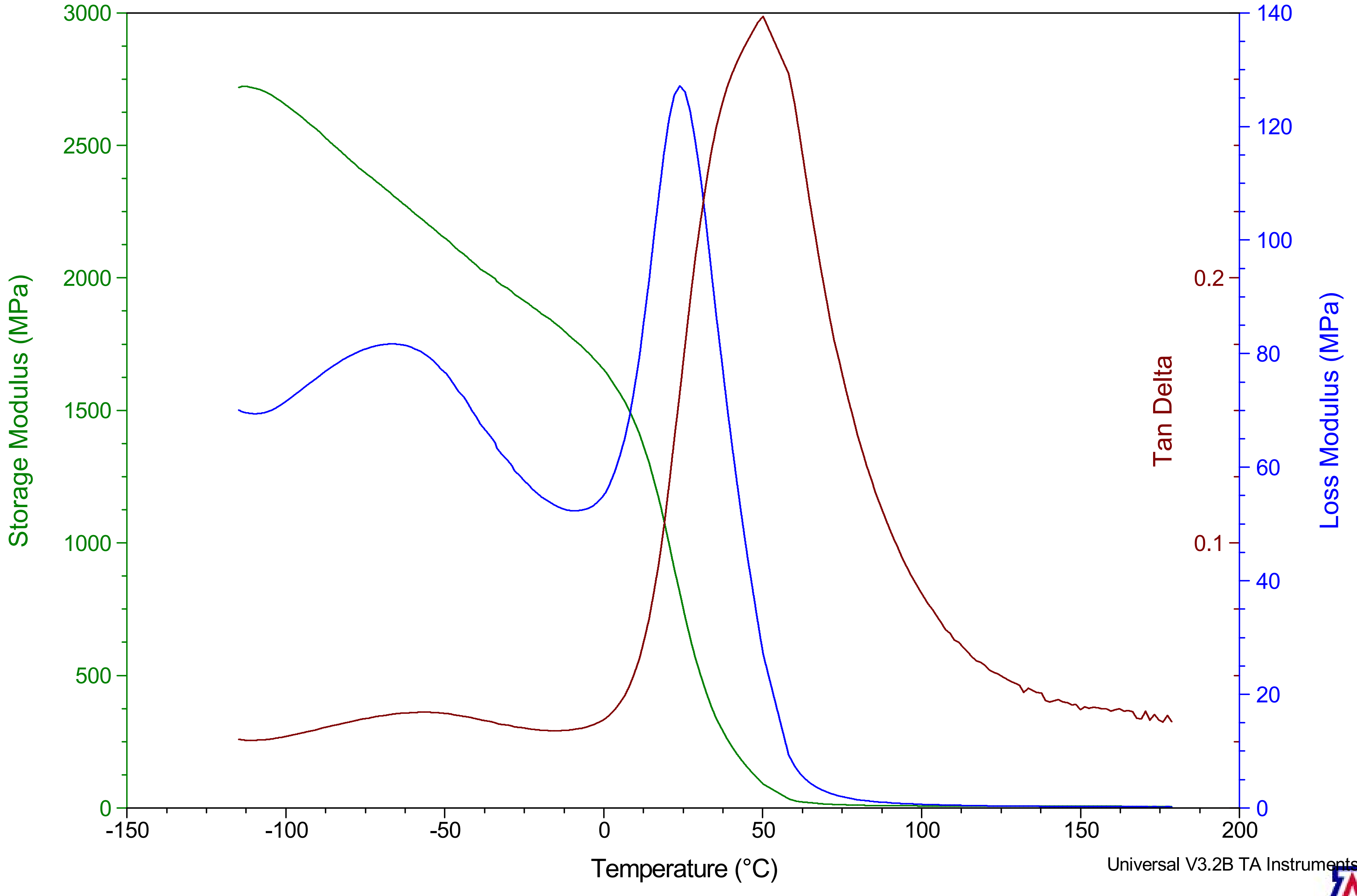
- DMA is used to determine material properties specific to the material's mechanical features (from –115 ºC to 180 ºC at 3 ºC/min)
- Generates results relating to a pad's dynamic moduli including:
  - Storage Modulus: Stiffness
  - Loss Modulus: Energy Dissipation
  - tan δ

$$\tan\delta = \frac{\text{Loss Modulus}}{\text{Storage Modulus}}$$

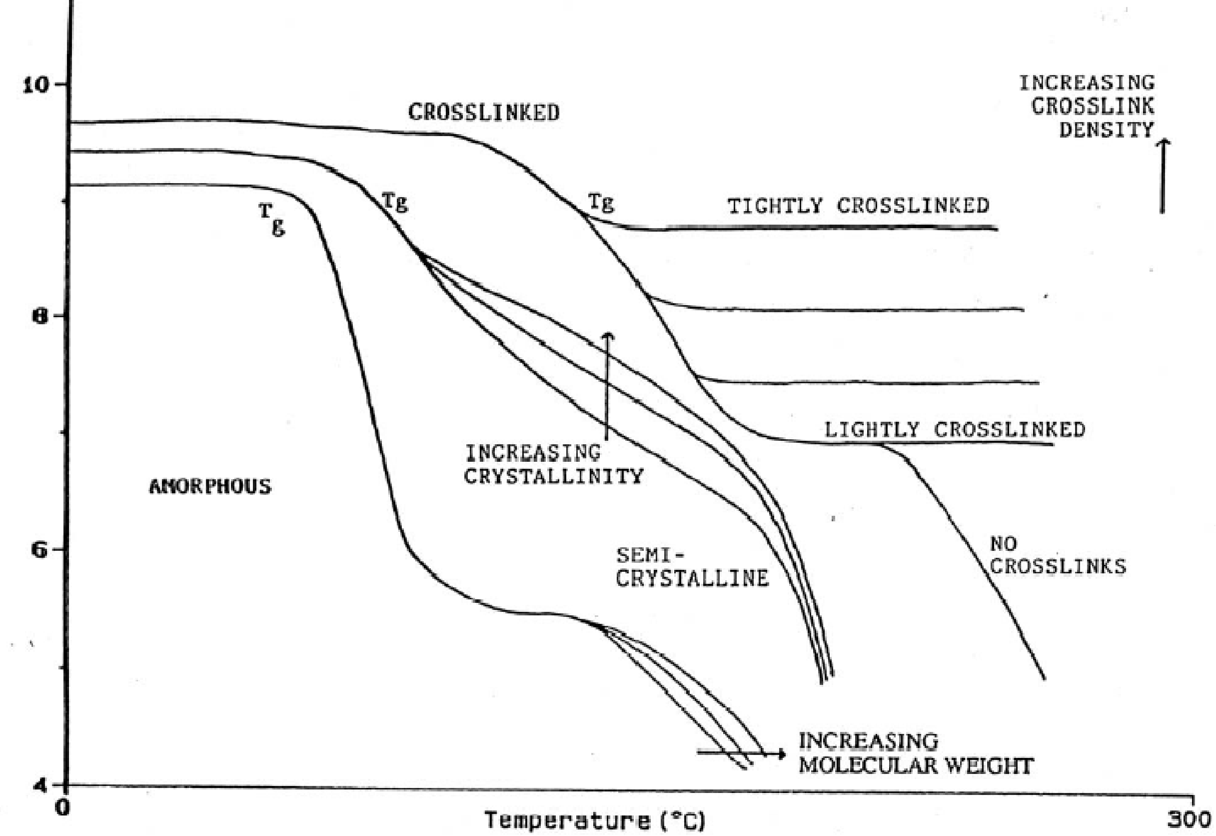
  - Glass Transition Temperature (T_g)
    - Evaluated through the loss modulus curve

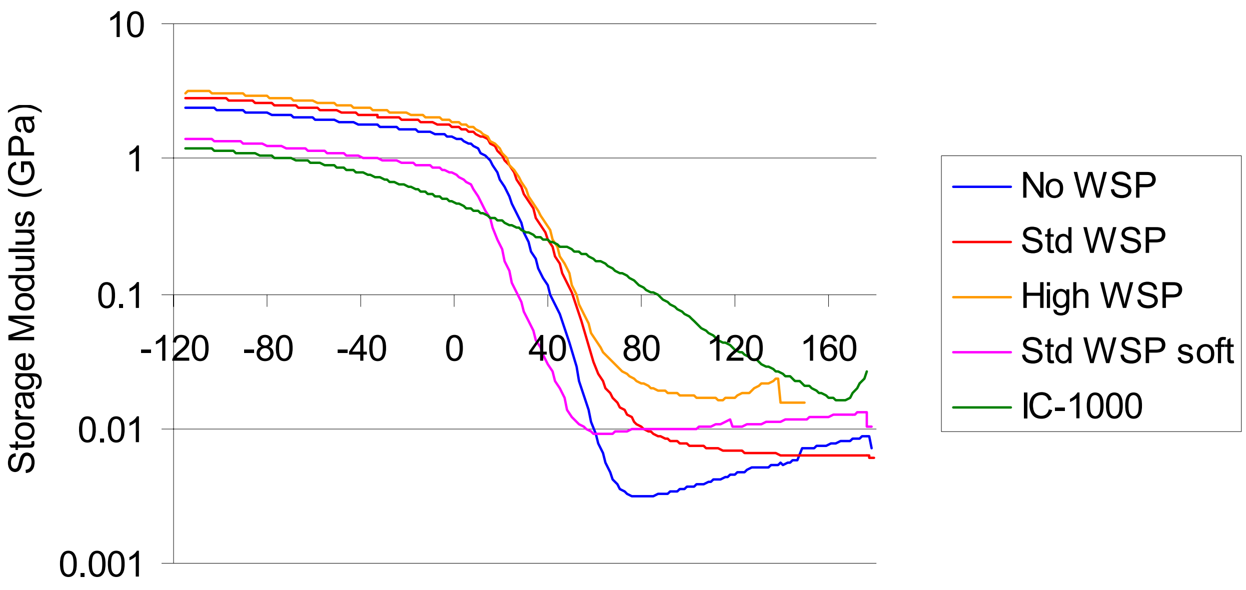


Dynamic-Mechanical Analyzer (DMA) Output



Storage Modulus





- IC-1000 is more tightly cross-linked than WSP pads

Source:
http://www.me.ust.hk/~mejswu/M
CH343/343Thermal-02.pdf

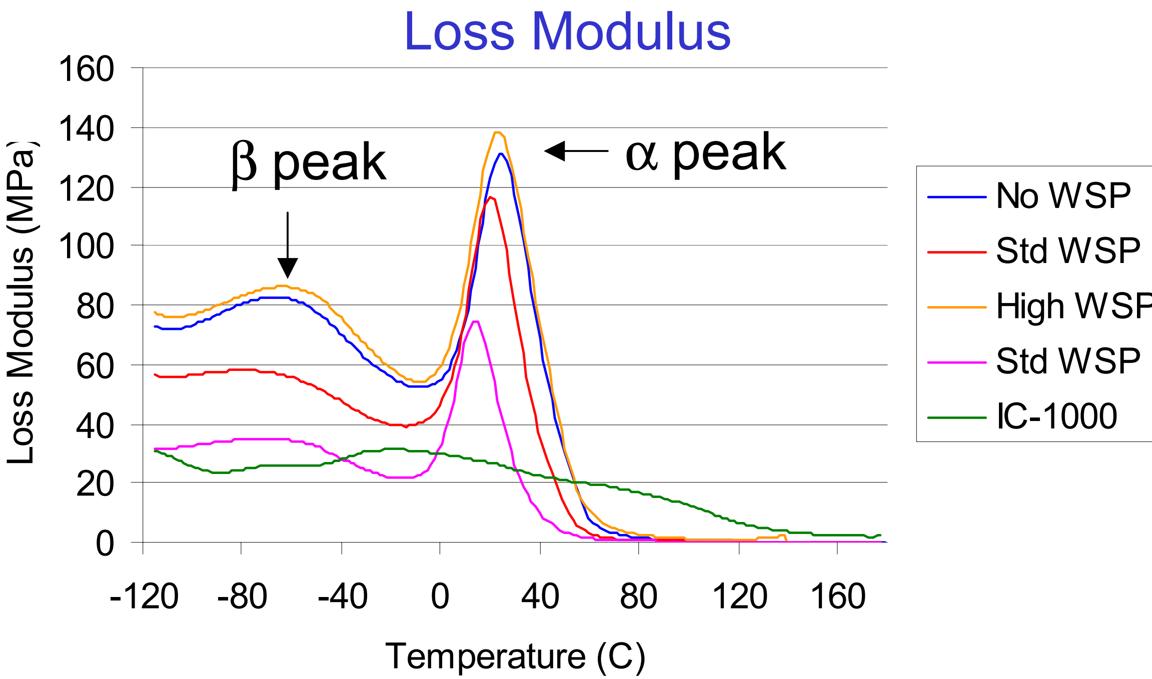
Glass Transition Temperature

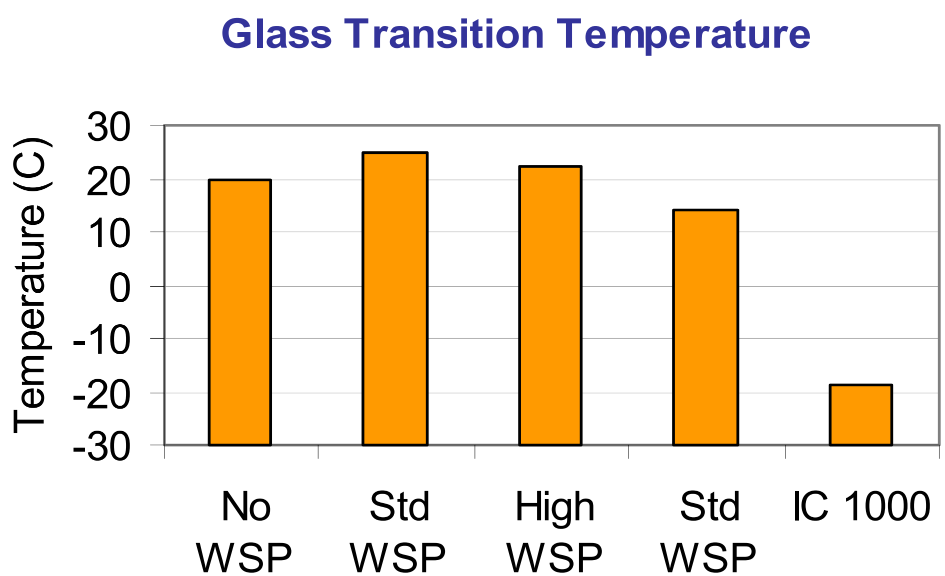
Glass Transition Temperature

- T_g: The temperature below which the mechanical properties of an amorphous polymer change from those of a rubber (elastic) to those of a glass (brittle)
- Alpha peak represents T_g (greatest change in modulus at the highest temperature)
- WSP pads exhibit T_g between standard CMP operating temperatures

Secondary Relaxation

- Beta peak represents movements of side chain groups in the polymer
- This is unique to JSR pads





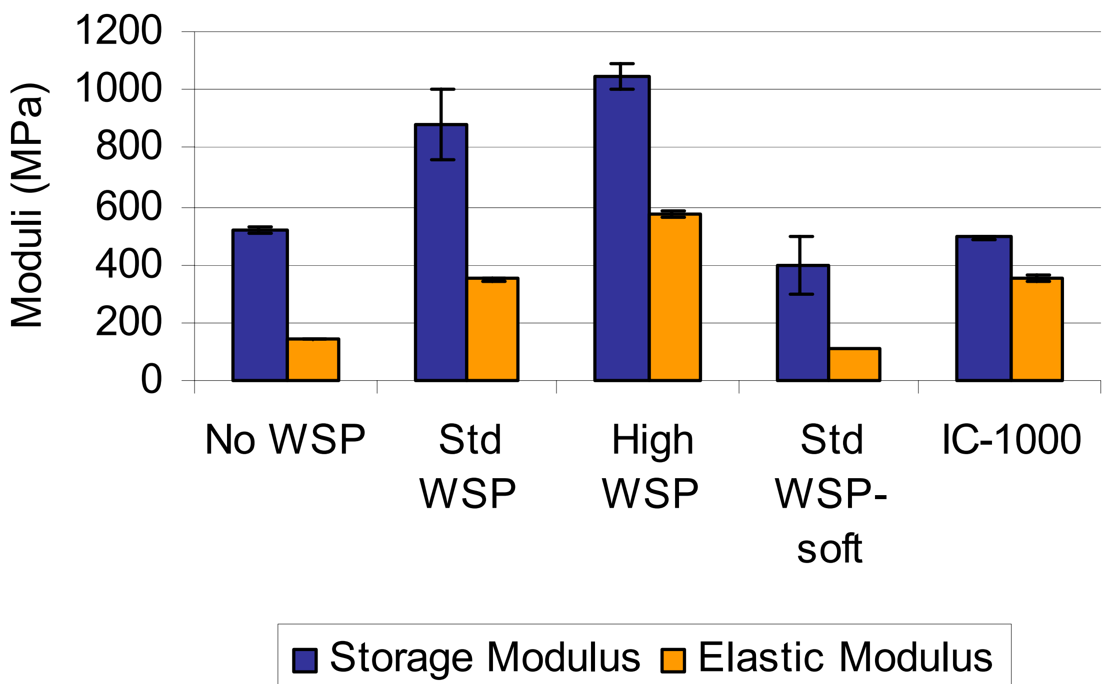
Comparison of Storage and Elastic Modulus

- **E*** = Complex modulus: a measure of the overall resistance to deformation
- **E'** = Storage modulus: elastic portion of the material
- **E"** = Loss modulus: describes the dissipation of energy into heat when a material is deformed
- **tan δ** = a measure of the phase angle between E" and E'

$$E^* = E' + iE''$$

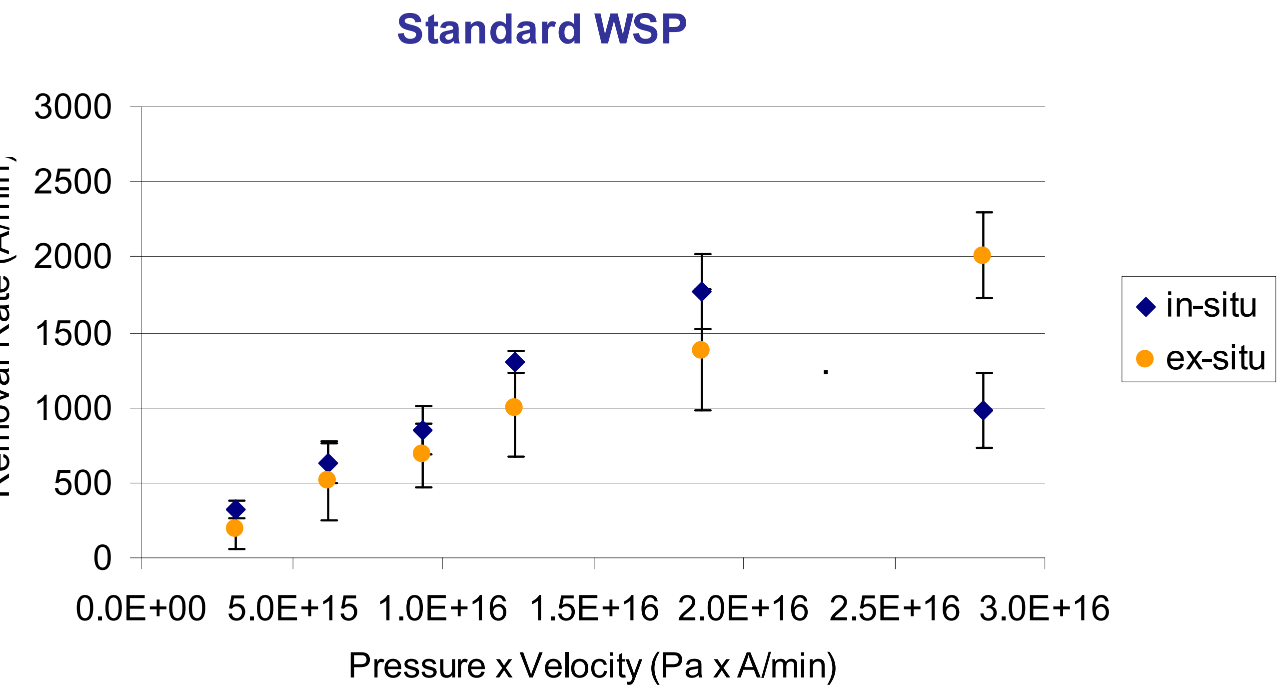
$$\tan\ \delta = \frac{E''}{E'} \rightarrow\ 0$$

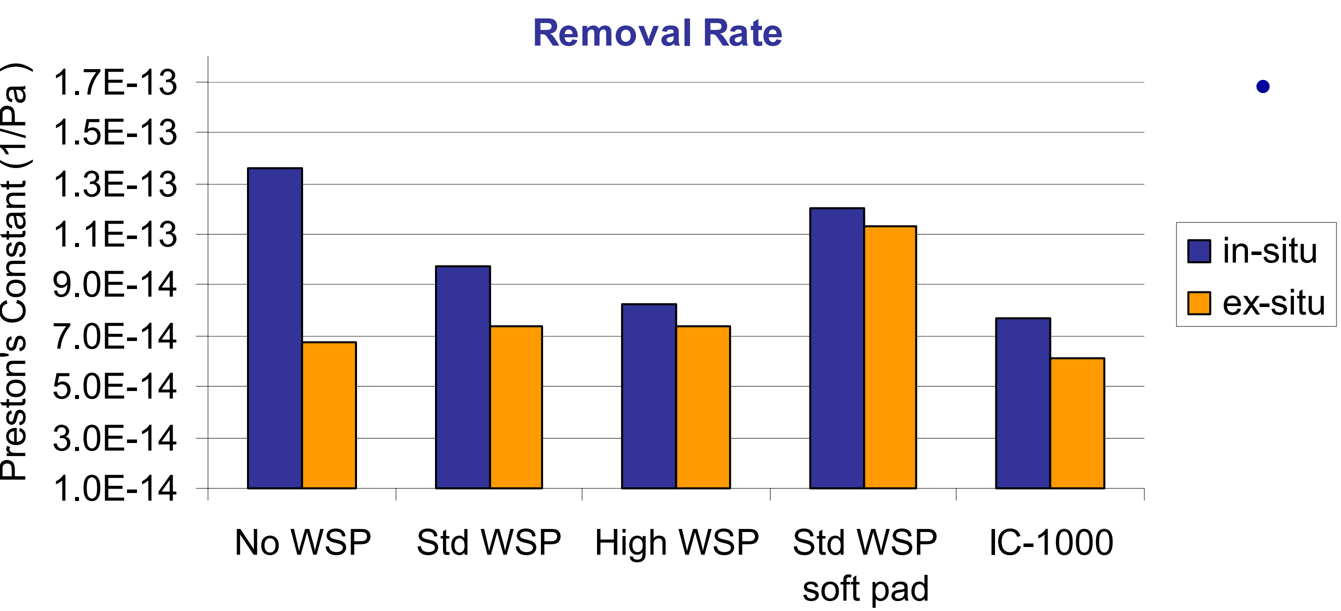
$$E^* \approx\ E$$



- The storage modulus does not approximate the elastic modulus
- JSR pads demonstrate more energy losses to heat than IC-1000

Pad Conditioning Schemes & Removal Rate



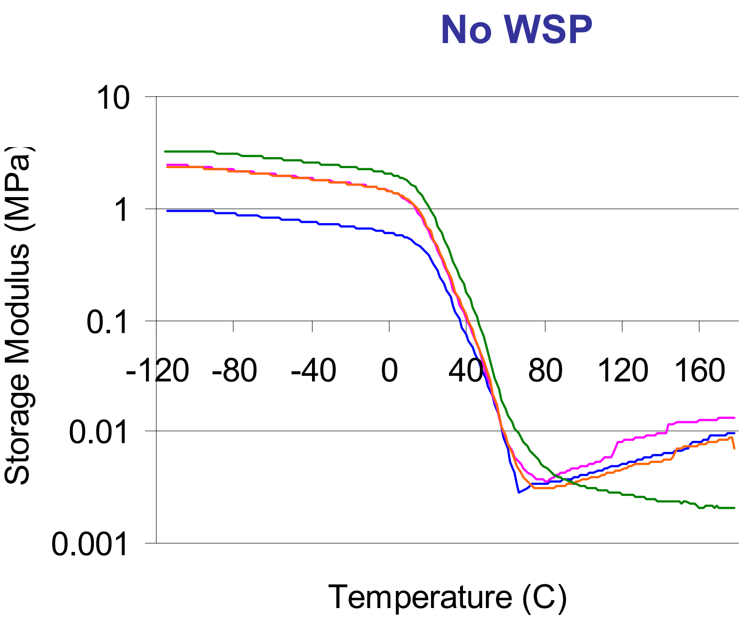


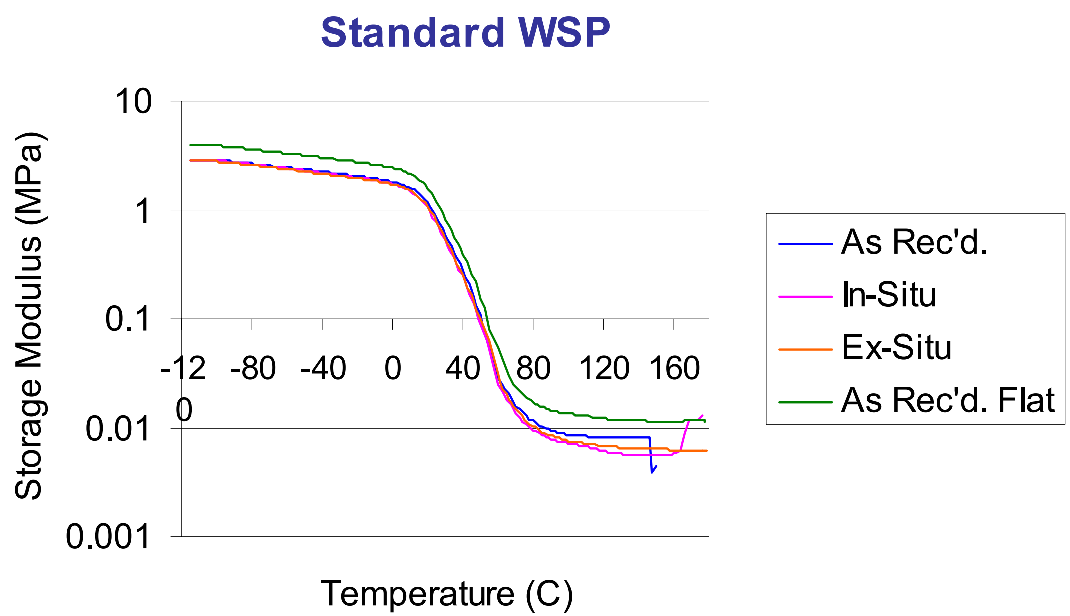
In-Situ:

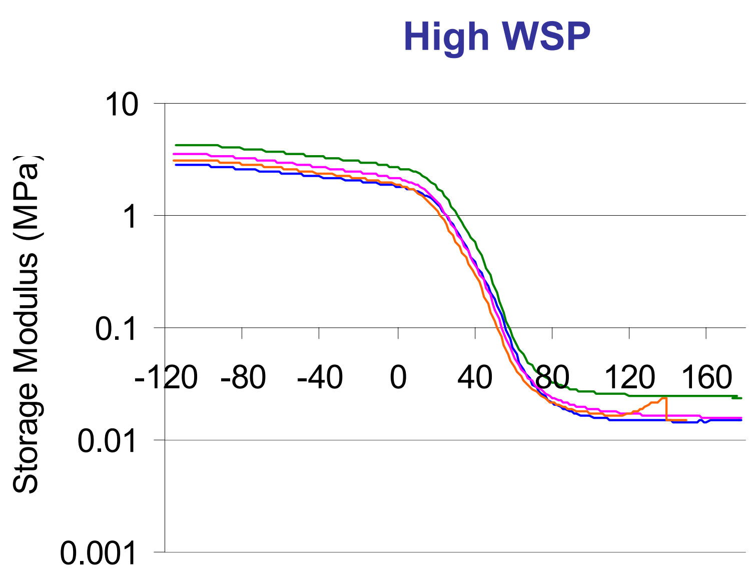
- There was a decrease in RR at the highest P x u setting (6 PSI x 0.93 m/s)
- Rate constant decreases with higher WSP content

- Ex-Situ:
  - Ex-situ conditioning resolves the anomalous behavior at high Pxu's
  - Higher WSP content does not effect the rate constant

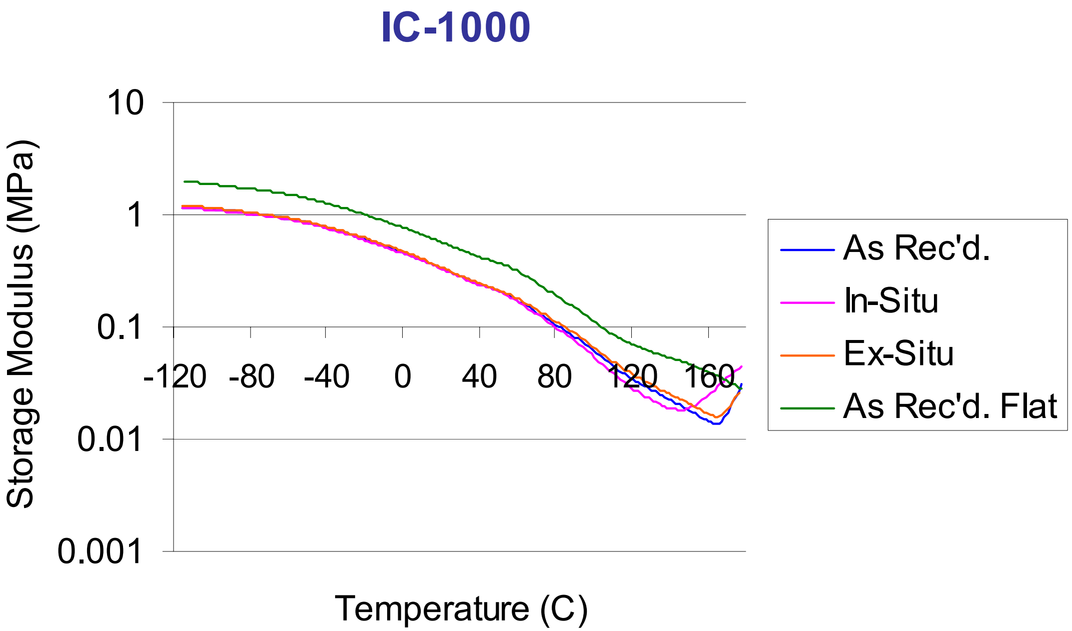
Storage Modulus for New and Used Pads







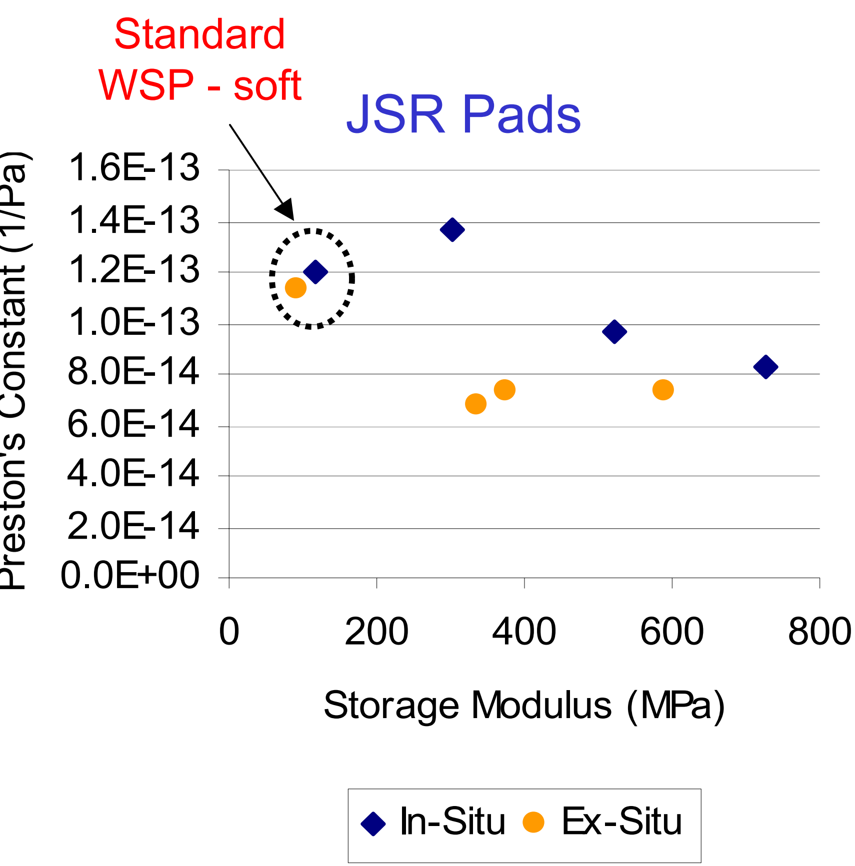
Storage Modulus for New and Used Pads

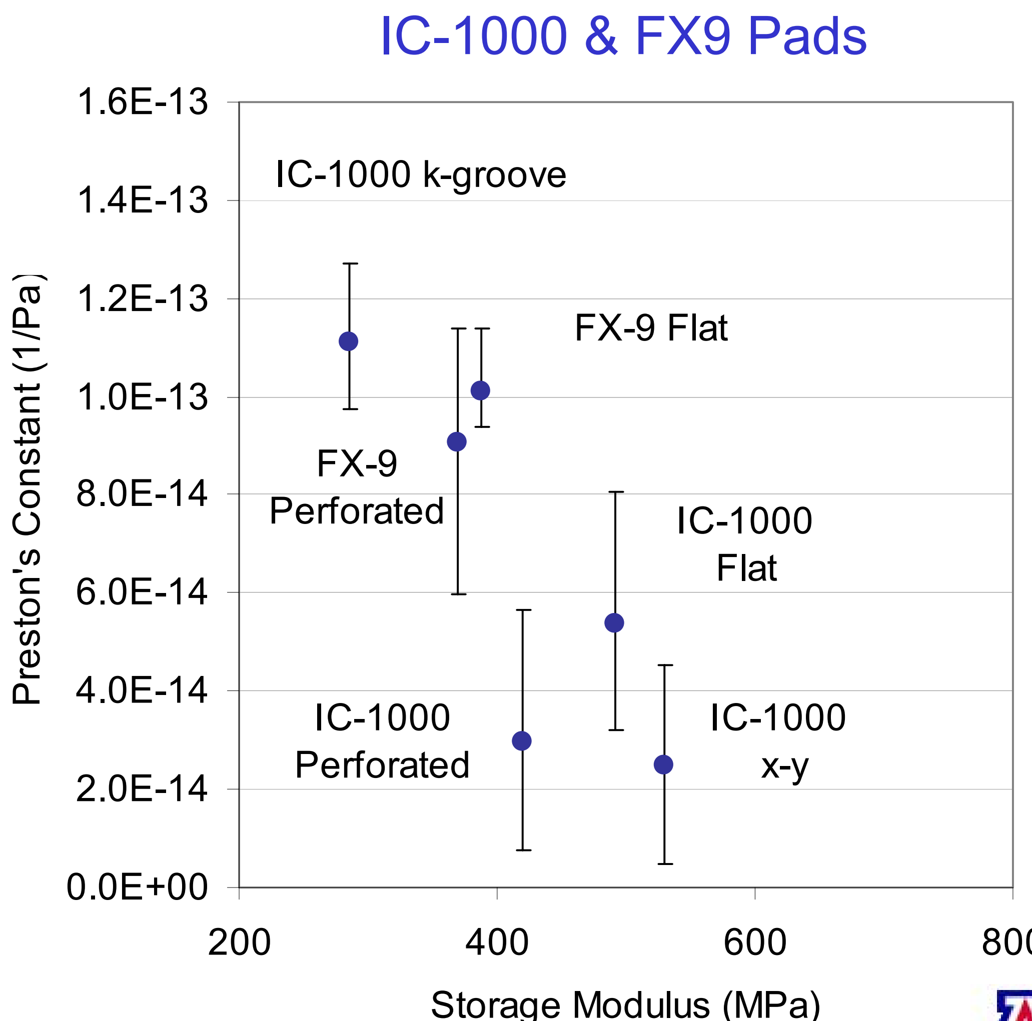


- The greatest modulus difference occurs between flat and grooved pads
- There is no obvious difference for new and used WSP grooved pads
- There is no obvious difference for new and used IC-1000 grooved pads

Hardness, WSP Content & RR Constant

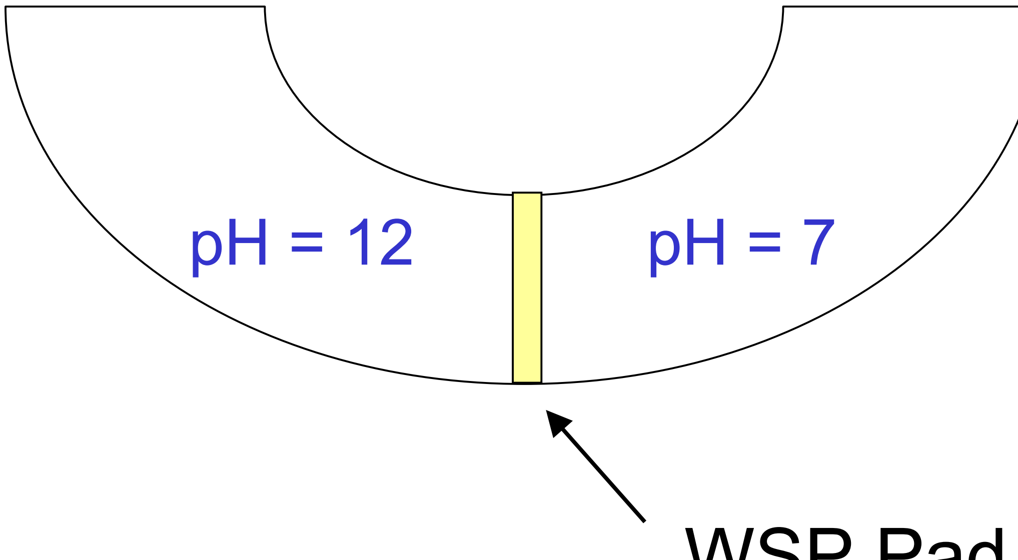
- In-Situ: Rate constant decreases as a function of hardness
- Ex-Situ: Rate constant does not have a defined trend with hardness





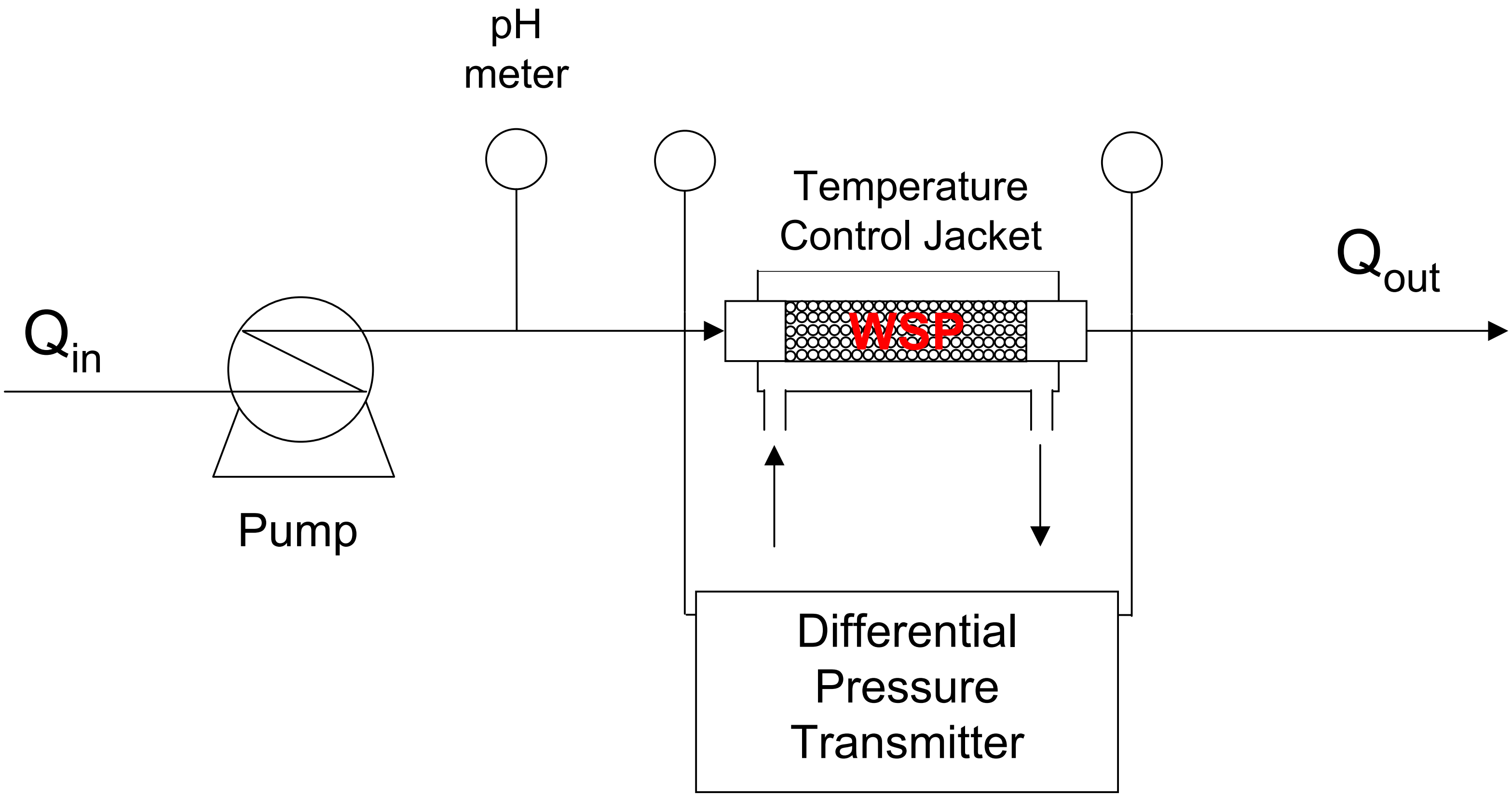
Future Plans: Permeability Experiment

- Motivation:
  - To estimate the amount of particles dissolved in the pad composition to determine whether pad conditioning is only a surface phenomena for WSP pads
  - Record pH change with time as basic solution dissolves WSP and permeates through the pad
  - SEM cross-section images of pad to determine permeation distance if no pH change is noted

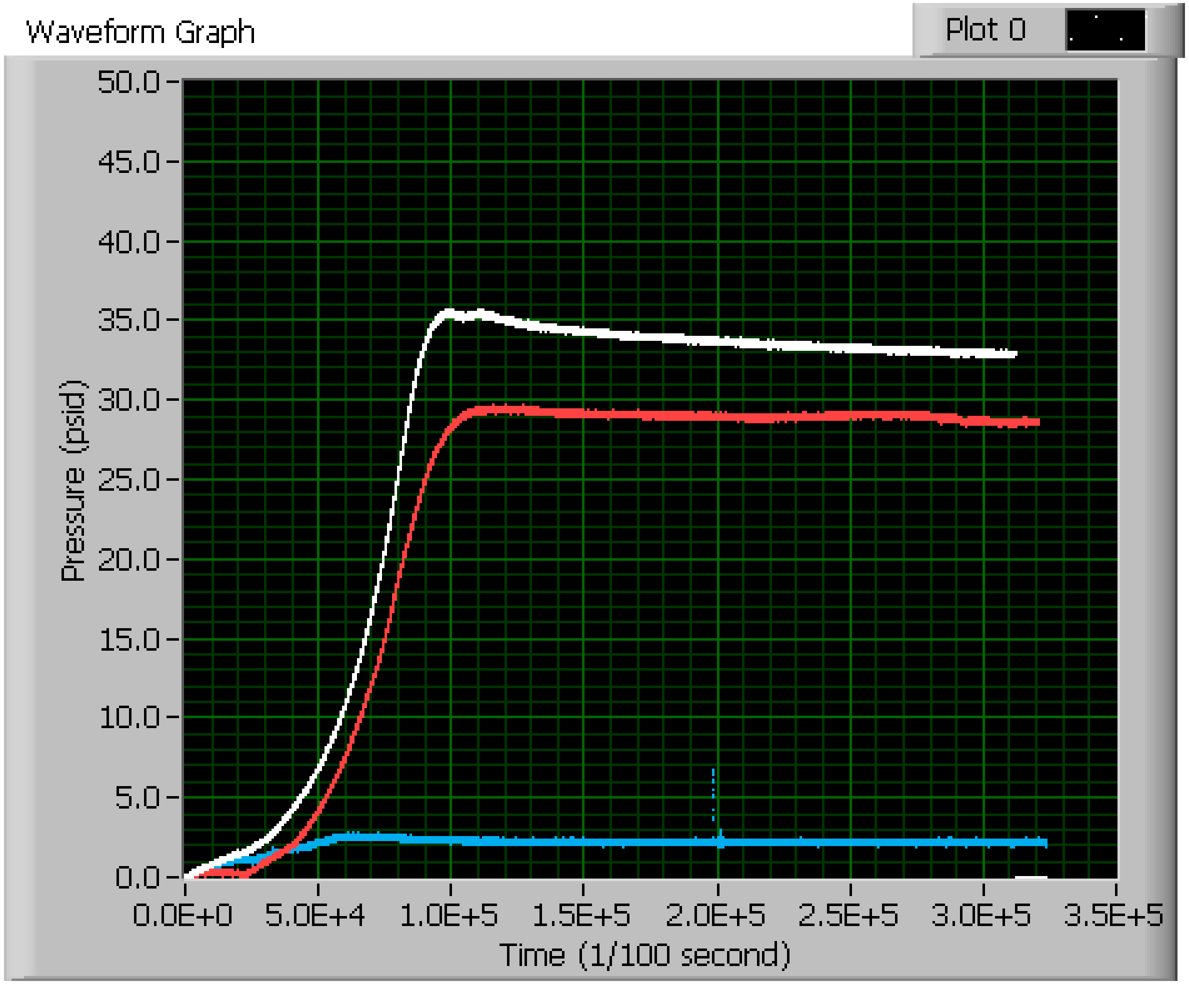


Determining the Dissolution Rate of the WSP

- Water Soluble Particles
  - Determine dissolution rates of WSP
  - Determine effect of temperature on WSP
  - Determine effect of pH on WSP



Differential Pressure Profiles with Various Solutes



- White – WSP
- Red – Table Salt
- Blue – Water (no solute)

Conclusions

- Characterized conditioning, tribological and removal rate behavior of WSP pads and compared to IC-1000
  - COF data shows that all grooved pads operate in boundary lubrication in the Stribeck-Gumbel Curve
  - Std WSP - Soft pad has the highest removal rate but does not have a higher average COF than the other pads

- Thermal analysis
  - Real time Infrared temperature measurements during CMP demonstrate large transient temperature regions
  - Shear forces cause the pad and slurry to increase in temperature up to 13 ˚C

- Developed and implemented DMA methods for pad characterization
  - Dynamic mechanical analysis show that most JSR pads have a Tg in standard CMP operating temperatures (20 to 40 ˚C) whereas the CMP performance of JSR pad is by no means inferior to IC-1000
  - There is no obvious storage modulus difference for new and used WSP grooved pads in the standard CMP operating temperatures

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