Multi-component Nanoparticle Based Lubricant Additive to Improve Efficiency And Durability in Engines

Dr. Atanu Adhvaryu (PI)
Caterpillar Inc.

"This presentation does not contain any proprietary or confidential information"

DOE Contract: DE-FC26-07NT43277

Aug 7, 2008

CATERPILLAR®

Outline

- ✓ Objectives
- ✓ Technical Challenges
- ✓ Approach
- ✓ Nano-lubrication mechanism
- ✓ Performance measures and key results
- ✓ Concluding remarks




Project Objectives (P1)

- Design and optimize process for nanoparticle synthesis
- Analyze shape, size, and surface properties
- Understand agglomeration and improve suspension of hybrid nanoparticles
- Lubrication mechanism and tribological behavior

Technical Challenges

- **Prevent progressive wear, lower friction and improve efficiency and durability in engine components**



CATERPILLAR®

Technical Challenges

- Prevent progressive wear, lower friction and improve efficiency and durability in engine components

- **Additive system for lubricants that will minimize sulfur and phosphorus content and lower ash forming elements (Low SAPS)**

Technical Challenges

- Prevent progressive wear, lower friction and improve efficiency and durability in engine components

- Additive system for lubricants that will minimize sulfur and phosphorus content and lower ash forming elements (Low SAPS)

- **Advanced lubrication technology for cleaner emission**

Technical landscape for SAPS

SAPS – Sulphated Ash, Phosphorus and Sulfur

- For HDEO (heavy duty diesel engine oil) SAPS are extremely effective for controlling wear, oxidation and limiting deposit formation. SAPS contribute to poisoning aftertreatment devices.



Technical landscape for SAPS

SAPS – Sulphated Ash, Phosphorus and Sulfur

- For HDEO (heavy duty diesel engine oil) SAPS are extremely effective for controlling wear, oxidation and limiting deposit formation. SAPS contribute to poisoning aftertreatment devices.

- SAPS will not go away soon. They will reduce over time. Industry sees great potential for Mo based technologies to control oxidation, wear and deposit control

Technical landscape for SAPS

SAPS – Sulphated Ash, Phosphorus and Sulfur

- For HDEO (heavy duty diesel engine oil) SAPS are extremely effective for controlling wear, oxidation and limiting deposit formation. SAPS contribute to poisoning aftertreatment devices.

- SAPS will not go away soon. They will reduce over time. Industry sees great potential for Mo based technologies to control oxidation, wear and deposit control

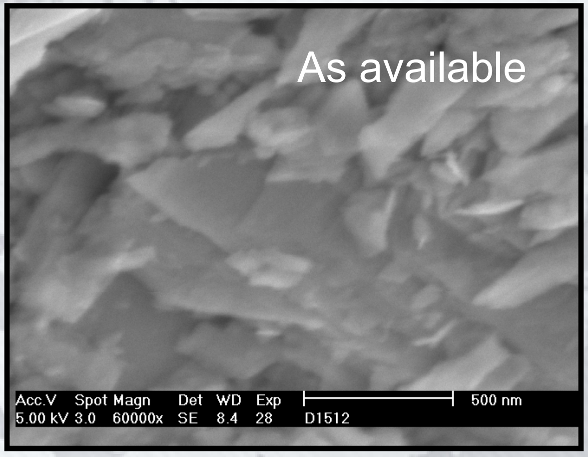
- leading OEMs and oil companies surveyed –
  Low- /no SAPS oil topped the list of emerging technologies (in next 5-10 yrs)

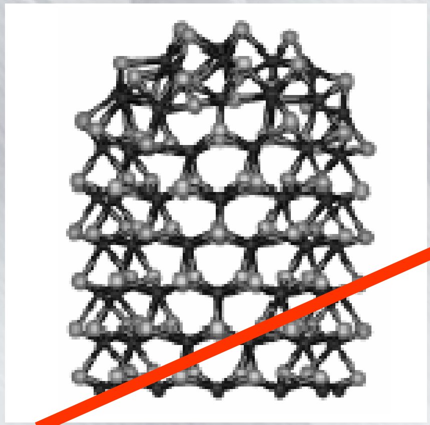
Different lines of defense

- **Coatings** (Good Antiwear agent and Friction modifier)
  - Get worn away with sharp asperities
  - Inert to additives
  - No easy replenishment possible
- **ZDDP** (Good Antiwear agent)
  - Needs activation so inadequate for cold start-up periods.
  - It forms hard antiwear protective films but increases friction.
  - New environment regulation is forcing low or no P molecules.
- **Solid lubricant as particles** (Good Antiwear and Friction modifier)
  - Micro particles settle in the oil.
  - Nanoparticles available agglomerate, do not disperse.
- **Organic agents** (Good Friction modifier)
  - Lack in required AW properties.
  - Excess might cause undesirable acid formation.

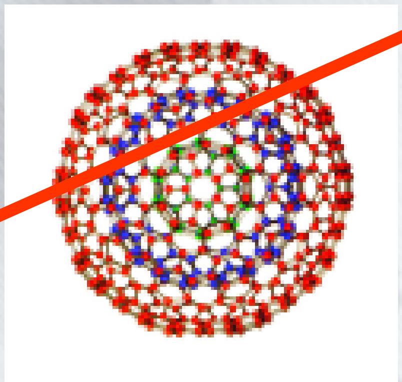


Approach

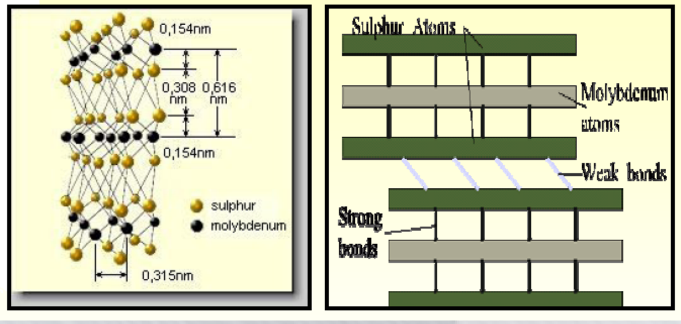




MS_2 nano tube



IF-MS_2 (fullerene structure)



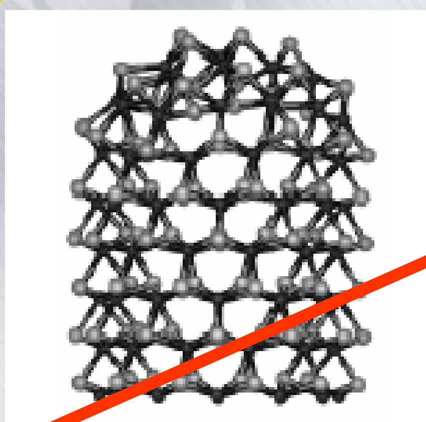
Conventional nanomaterials

Approach

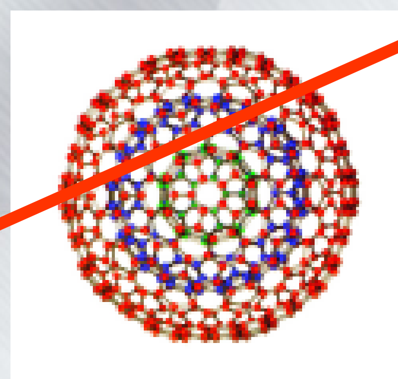
Top down particle architecture

Multi-component

Surface stabilization and dispersion

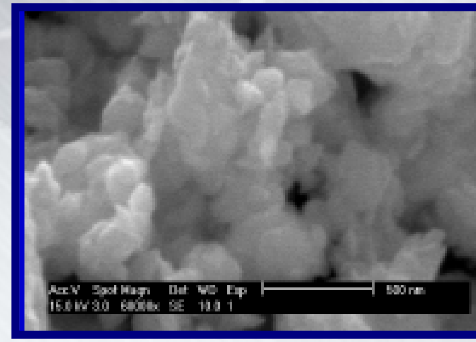


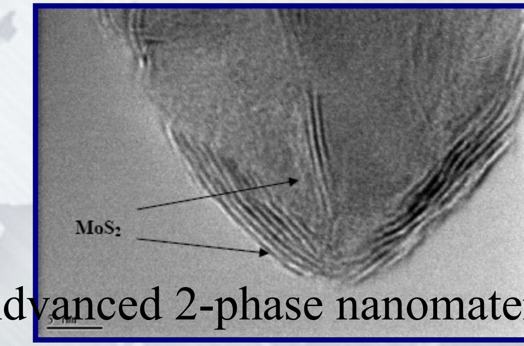
MS$_2$ nano tube



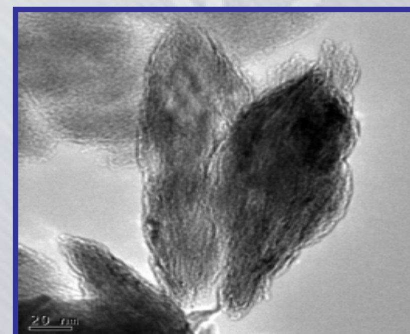
IF-MS$_2$ (fullerene structure)

Conventional nanomaterials



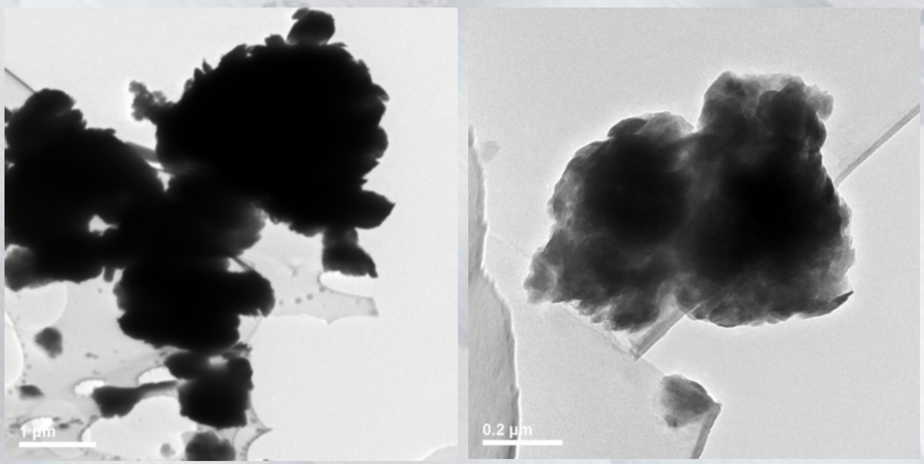


Advanced 2-phase nanomaterial



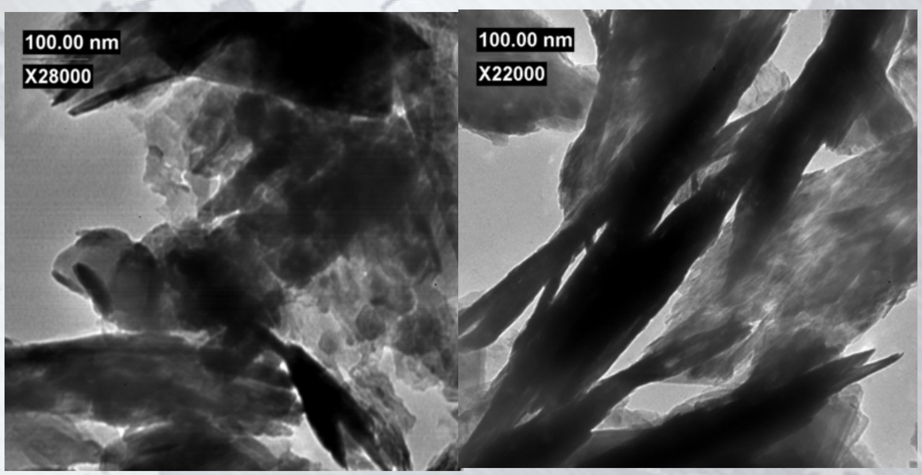
Chemo-mechanical Process

Dry Process



Fractured small particles are aggregated due to increase in surface energy

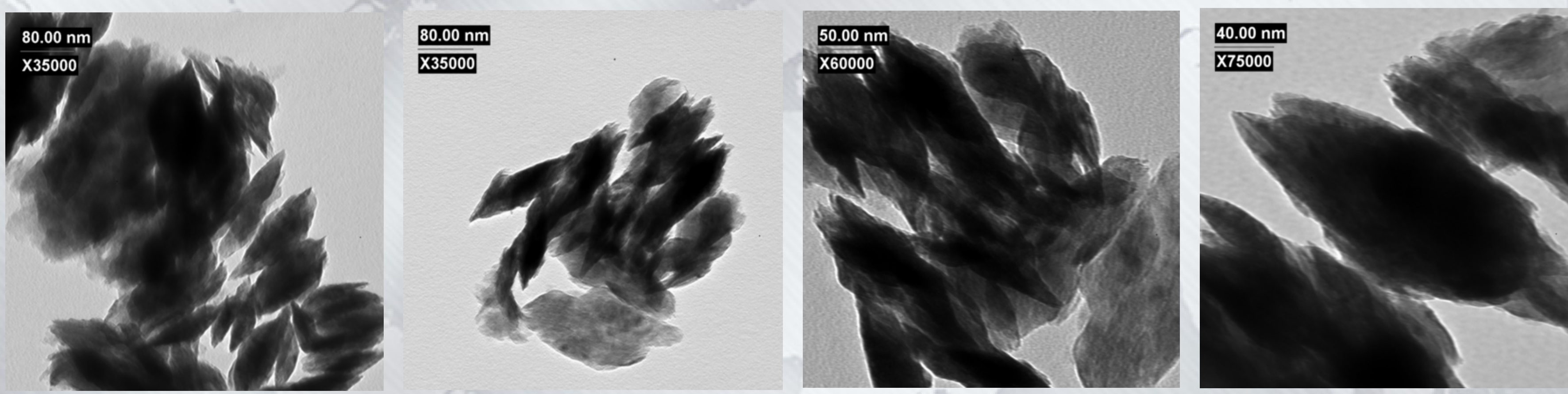
Wet Process



Exfoliates planar layers
No size reduction
Surface passivation

Hybrid Process (method of choice)

The hybrid milling process is a combination of dry milling and wet milling process



TEM graphs of hybrid milled MoS_2 with dry milling step followed by oil milling step

- Combination of high energy milling to decrease the particle size and use oil to prevent particles from fusing - will result in monodispersed particles



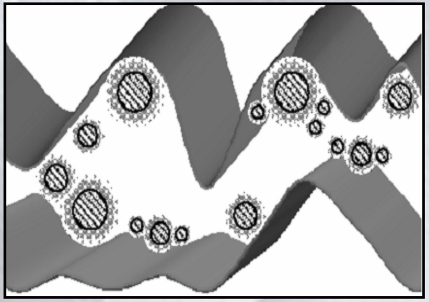
Technical Advantages

- Nanometric size: allows them to easily enter the surface asperity contact area

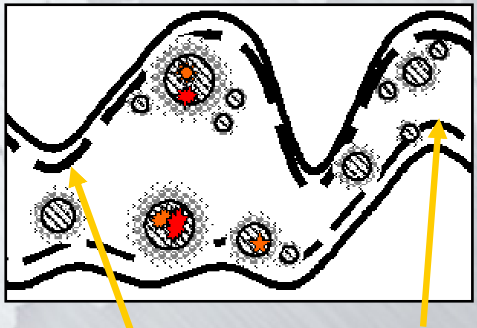


Technical Advantages

- Nanometric size: allows them to easily enter the surface asperity contact area
- Weak inter-planner bonds: delamination under high contact stress



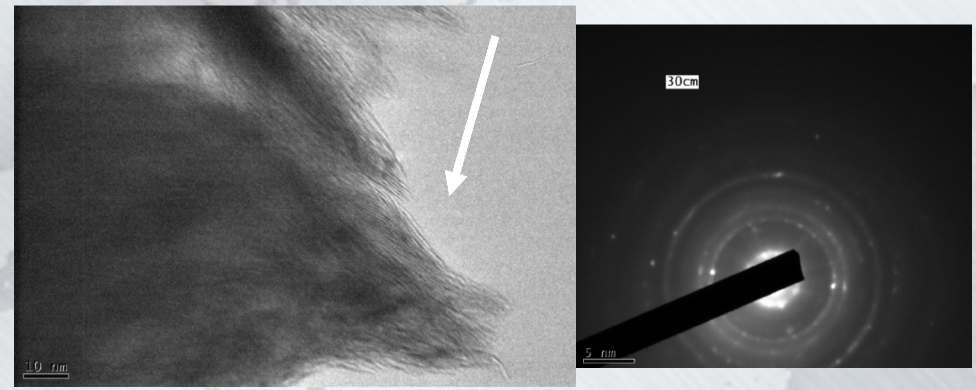
Particles are not depleted in low load environment

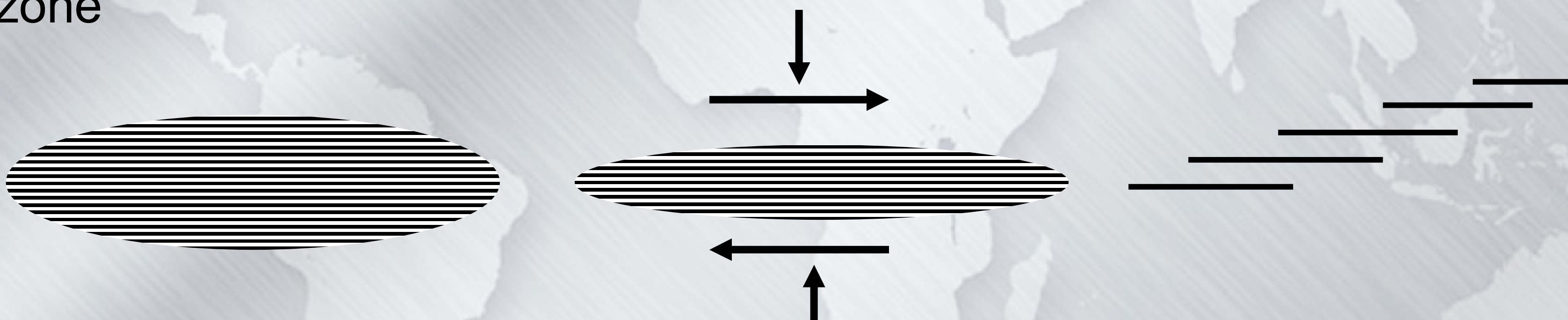


Transfer layer on asperity contact

Lubrication Mechanism

- Pressure sensitive architecture
- Exfoliation of external lamellar sheet
- Transfer of lamellar sheet (active component) to the contact zone





Undeformed (Hydrodynamic)

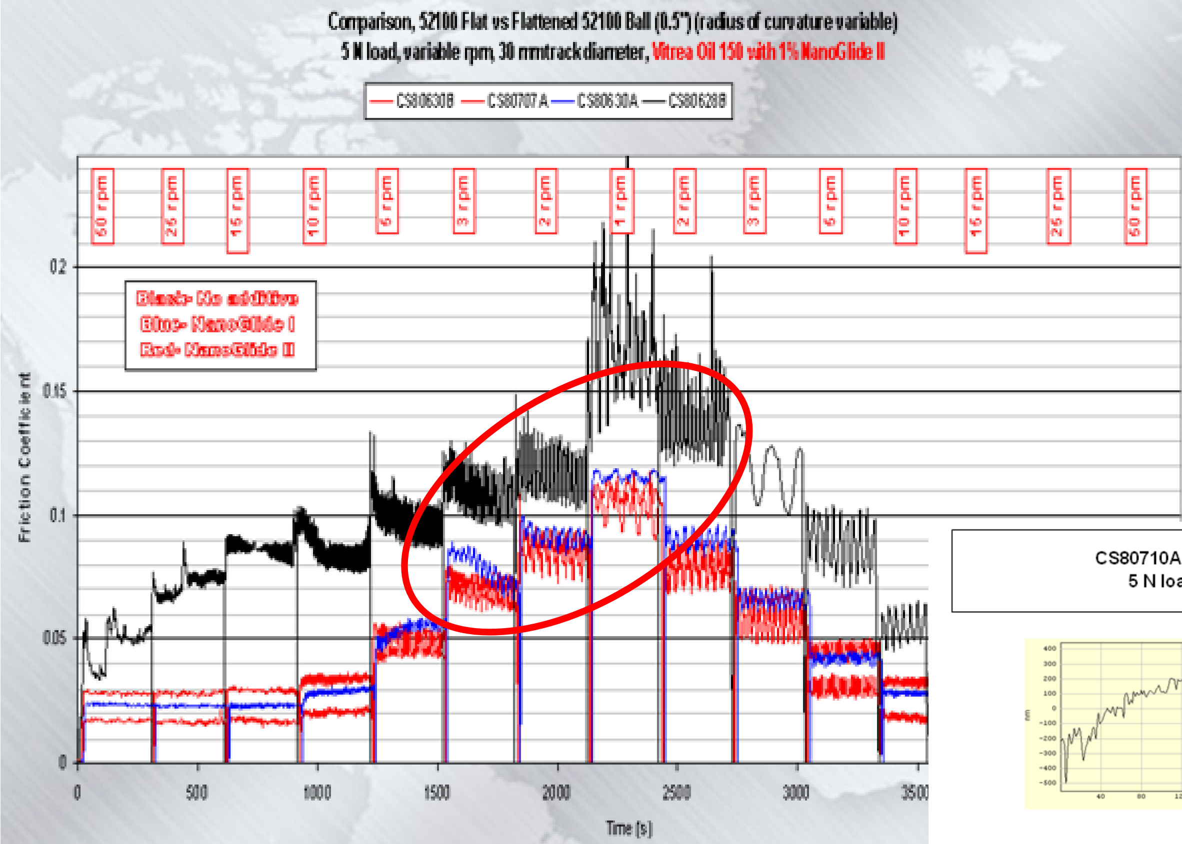
Deformed (Mixed)

Fractured (Boundary)

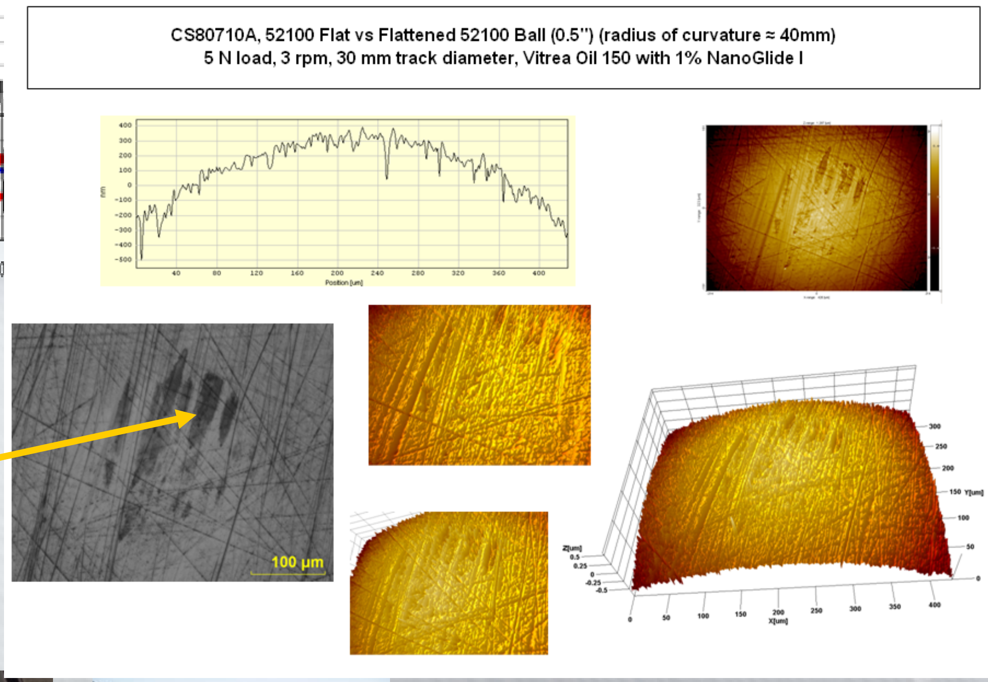
Tribology of nano-lubricants



CATERPILLAR®

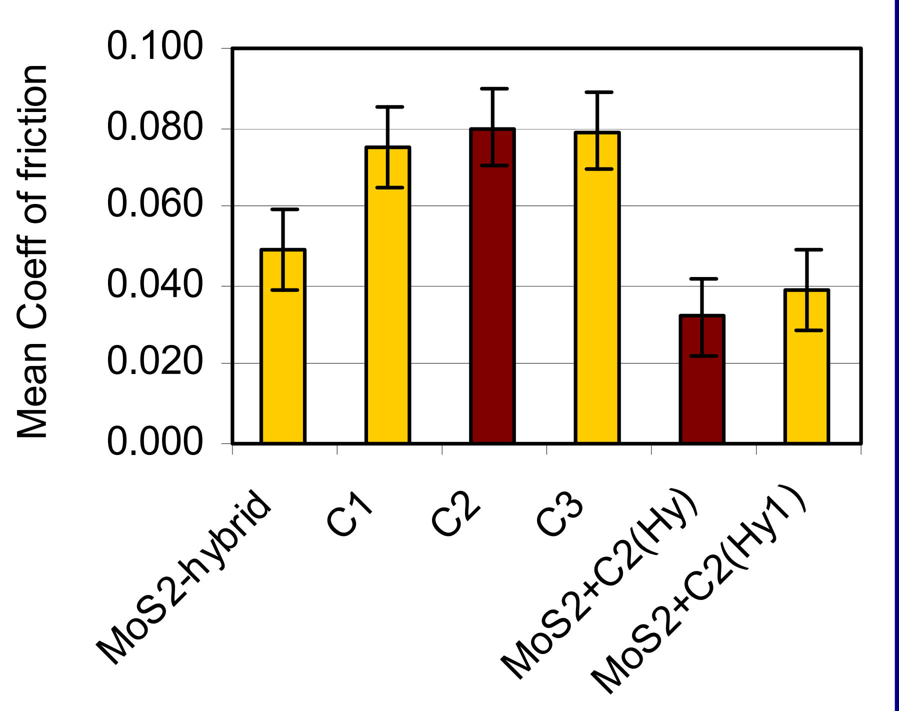


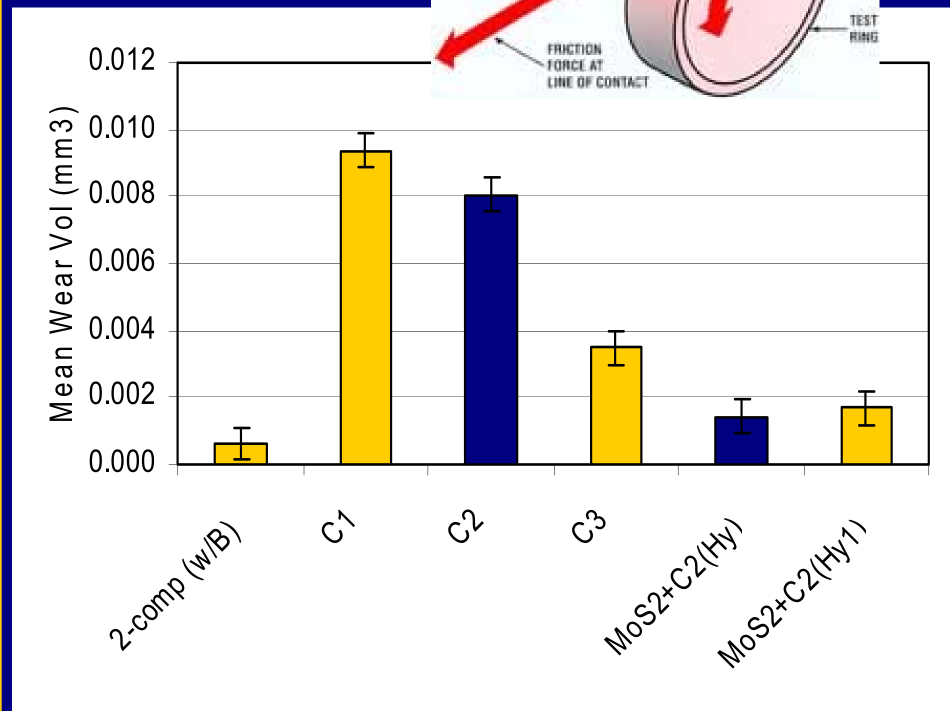
20 - 40% reduction in friction in BL regime

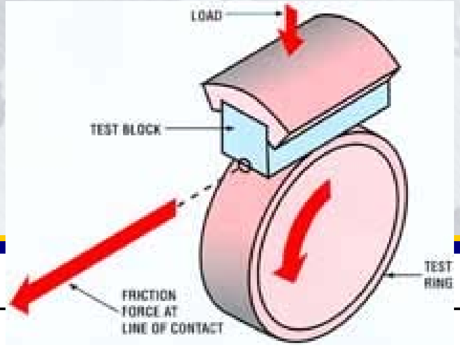


Evidence of MoS_2 transfer layer on surface

BOR wear test; unidirectional

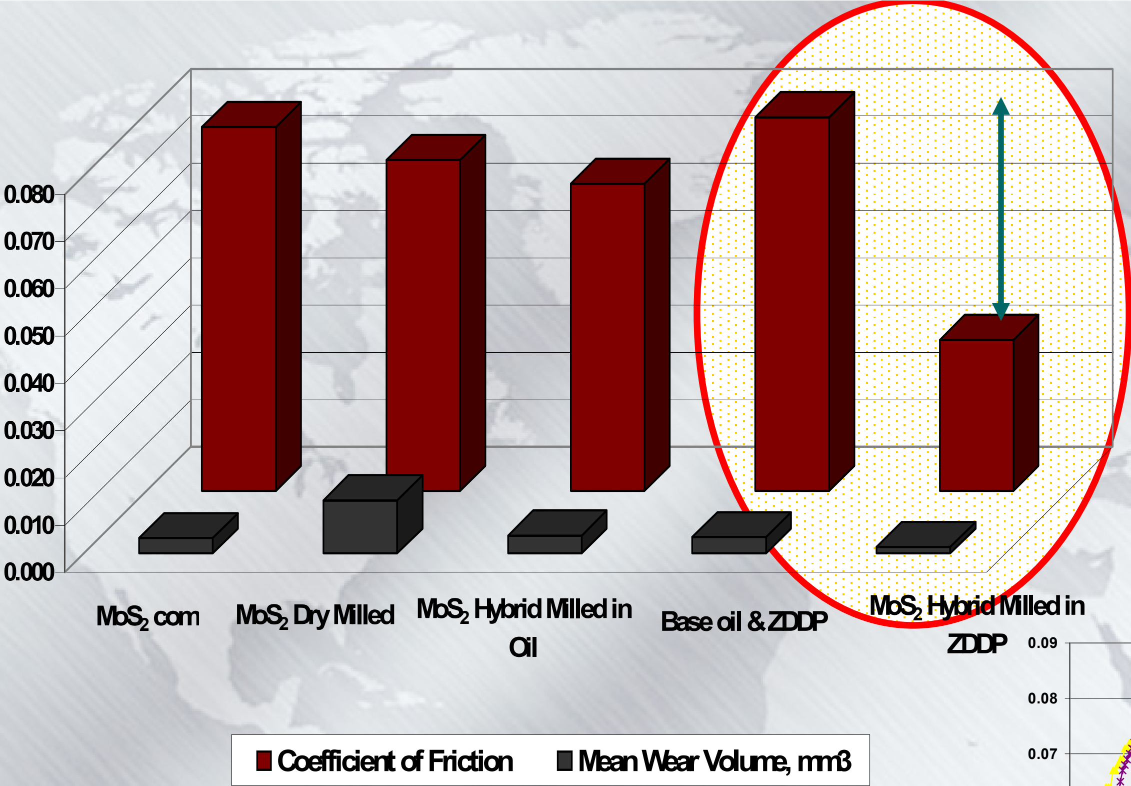






- **Nano materials highly effective in reducing friction & wear**

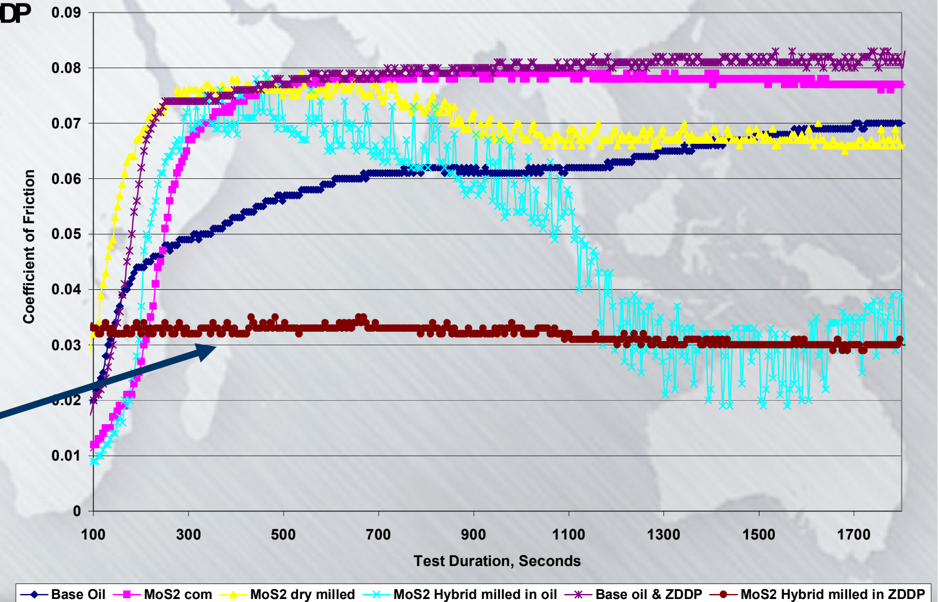
Block on Ring COF and Wear Volume



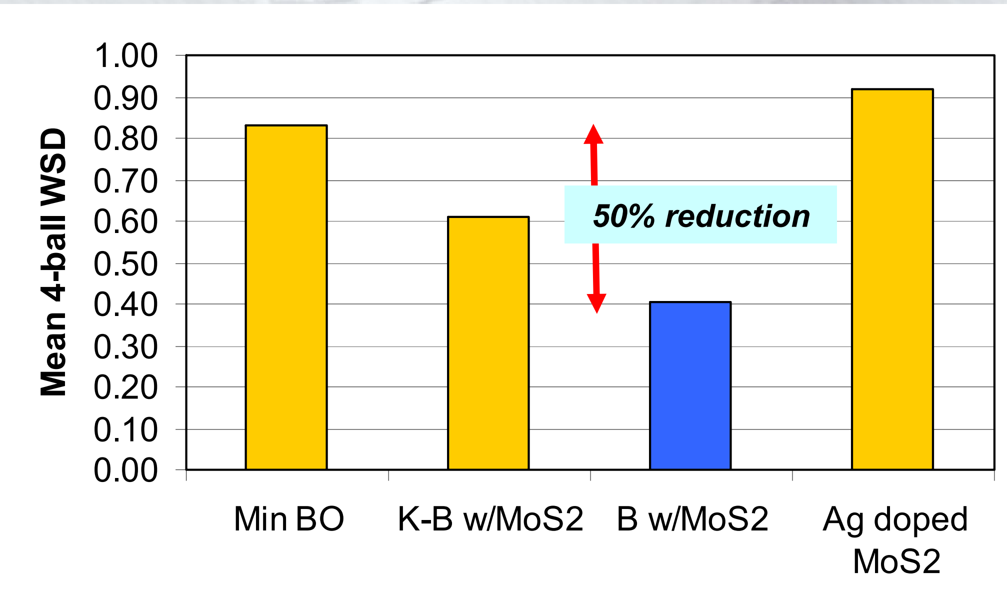
50% reduction in COF w/ nanomaterials

Nanomaterials

Effective from the 1st cycle

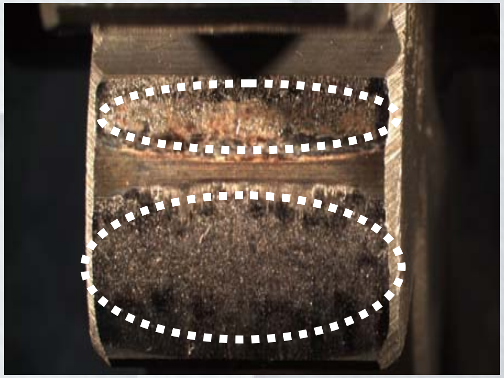


CATERPILLAR®

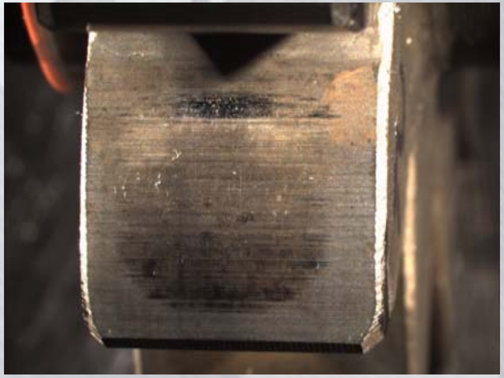


Industry specified test ASTM D 4172

Cat FZG Gear scuffing test with nano-technology



Base stock
Load = 239.3 Nm
Scuffed



Base stock w/nano particle
Load = 304 Nm
No scuffing

Key Elements of nano-lubrication Technology Leadership

Control the Business Where it Counts

- Engine
- Aftertreatment
- Transmission
- Hydraulics
- Undercarriage

Control Core Competencies

- Efficiency
- Durability
- Combustion/Emissions
- Cooling

How will we win ?

- ✓ Success through an integrated approach to lower SAPS and improve AT performance for engine systems solution

- ✓ Deliver high efficiency lubrication with more power density and increase component life

- ✓ Long term success through energy efficient nano-lubrication technology

CATERPILLAR®

Concluding Remarks

- *Technology Potential* - Advanced lubrication for engine with potential to reduce friction and wear characteristics and low SAPS
- *Approach to Research* - Novel nanomaterial technology with active particle architecture
- *Technical Accomplishments* –
  - ✓ A manufacture friendly process
  - ✓ Understand transfer layer lubrication mechanism
  - ✓ Particle stabilization process
  - ✓ Reduction in friction and wear (20 – 40%), Low SAPS
- *Tech Transfer* - Offers a nanomaterial technology for low friction / wear in engine with cost and scale-up analysis



CATERPILLAR®

Acknowledgement

DOE Support: DE-FC26-07NT43277

- University of Arkansas
  - Prof. Ajay Malshe
  - Dr. Demytro Dimydov
  - Arpana Verma
- NanoMech LLC
  - Dr. Wenping Ziang
- Argonne National Lab
  - Dr. Ali Erdemir
  - Dr. Osman Eryilmaz



Thank you



CATERPILLAR®