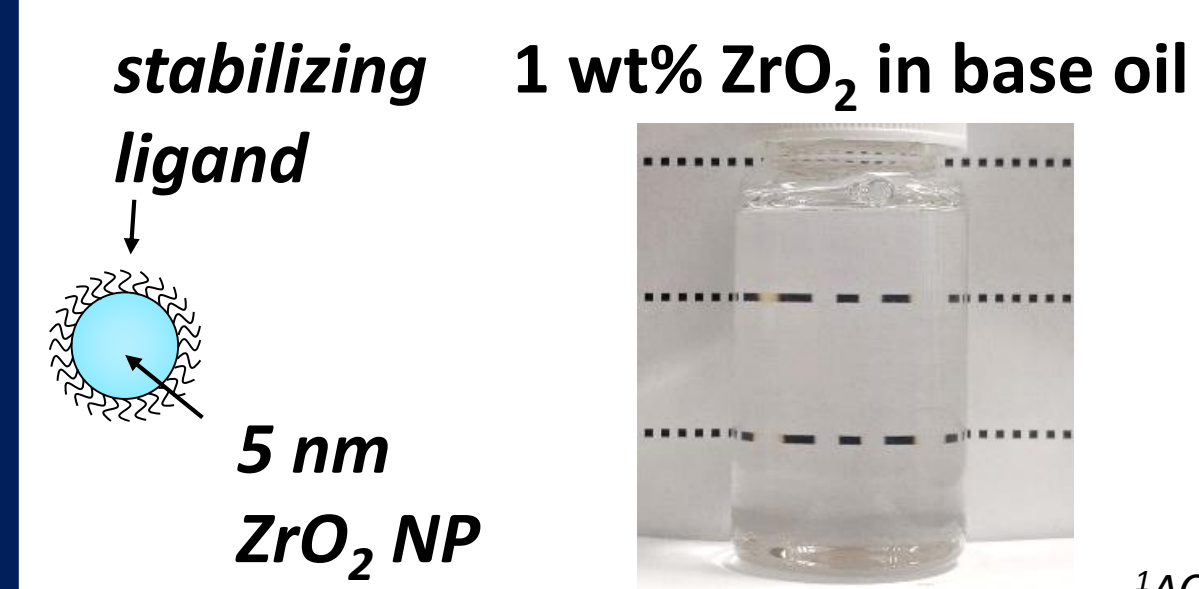
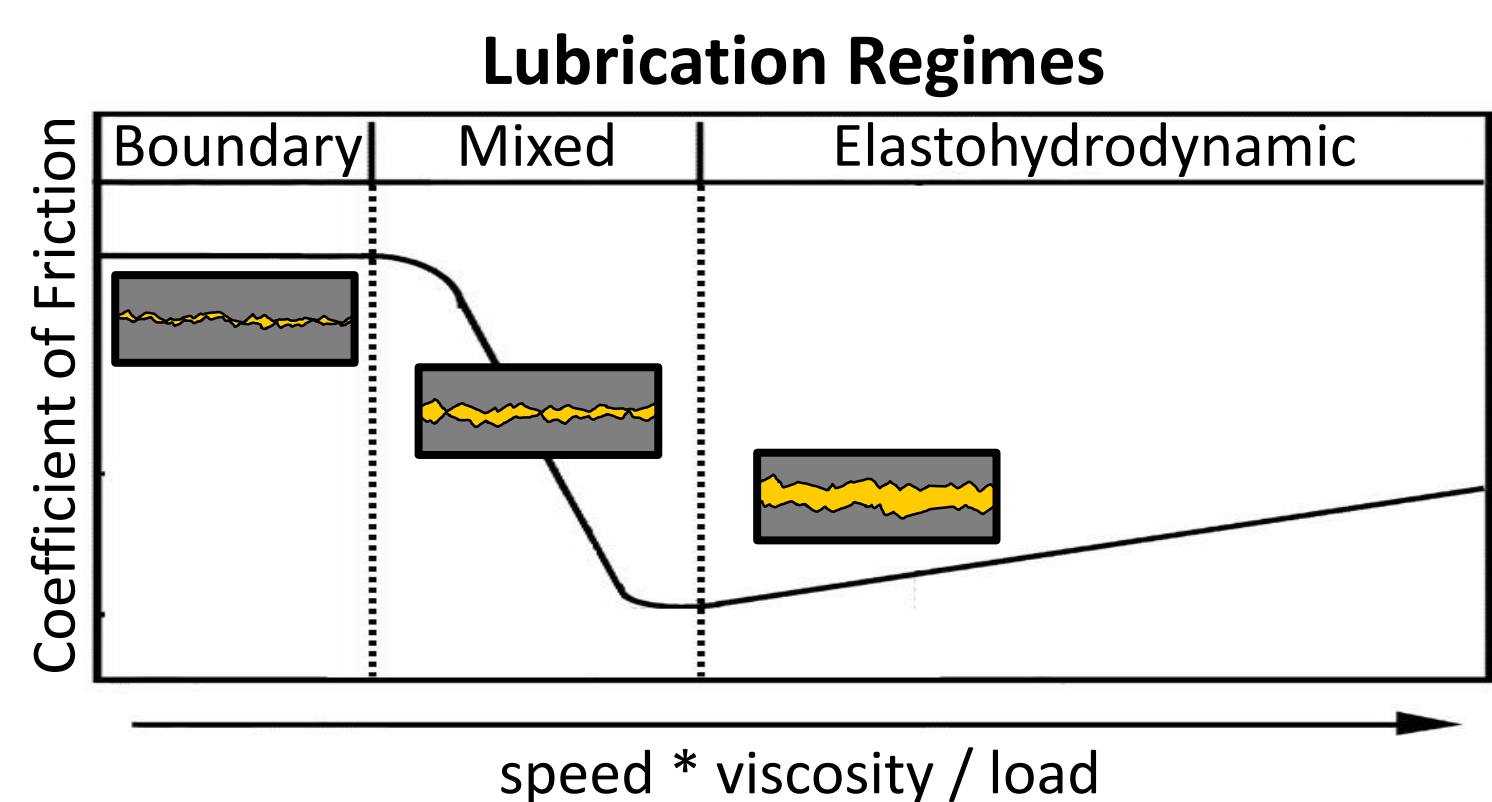


# 1. ZrO<sub>2</sub> Nanoparticles as Antiwear Additives

Lower viscosity gear oils minimize viscous energy losses in machines but increase the risk of wear from boundary contact. To protect surfaces, improvements in antiwear (AW) additives are needed.

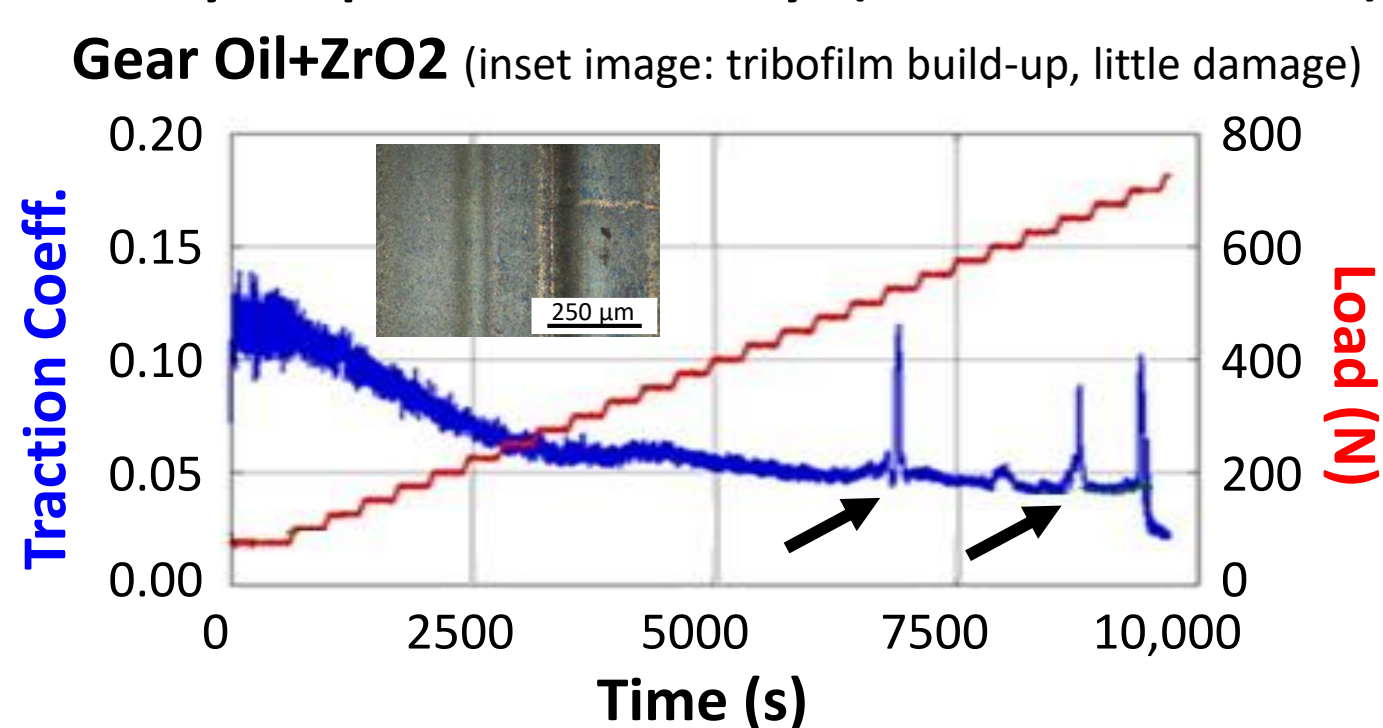
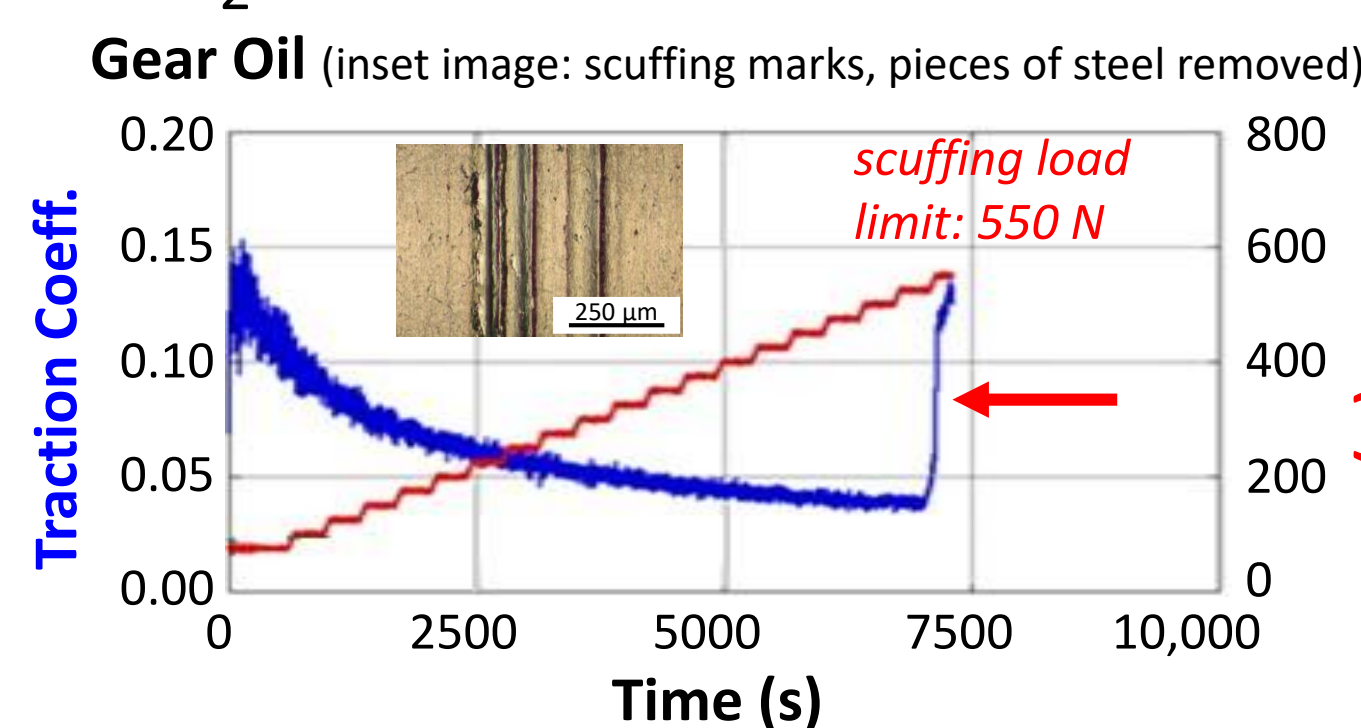


ZrO<sub>2</sub> nanoparticles (NPs), a promising AW candidate, form clear dispersions in base oil.

In sliding contact, mechanical stresses drive the formation of AW ZrO<sub>2</sub> tribofilms.<sup>1,2</sup>

<sup>1</sup>ACS Appl. Mater. Interfaces 2018, 10, 46, 40335-40347. <sup>2</sup>Nano Lett. 2018, 18, 11, 6756-6763.

In steel-on-steel macroscale tests<sup>3</sup> ZrO<sub>2</sub> NPs protect the interface from scuffing: in gear oil there is total failure via scuffing (red arrow), but in gear oil+ZrO<sub>2</sub> there are force excursions followed by rapid recovery (black arrows).

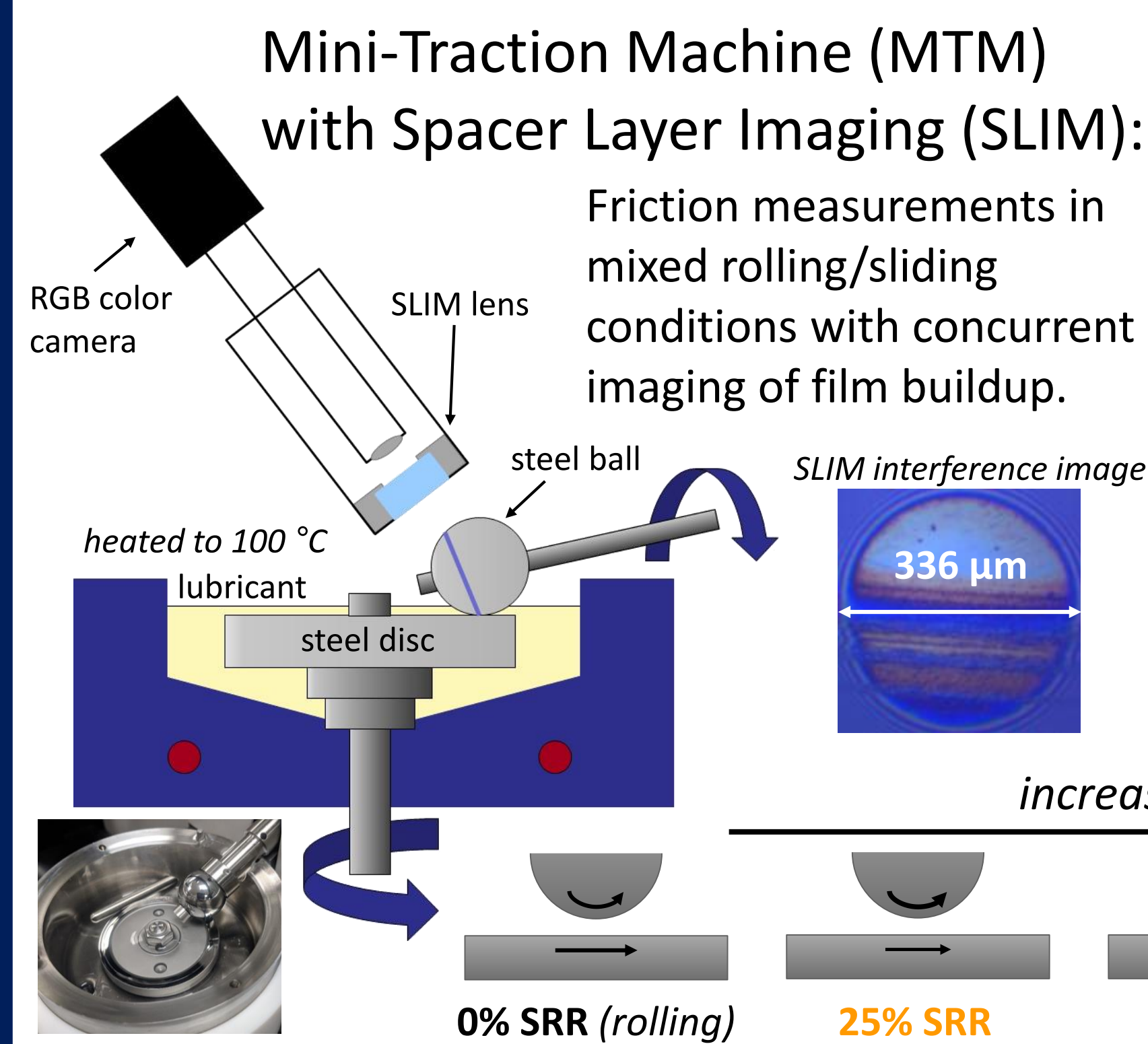


<sup>3</sup>Demas, N.G. et al. Scuffing Performance of Low-Viscosity Gear Oil Containing ZrO<sub>2</sub> Nanocrystals, Proceedings of the STLE/ASME Intl. Joint Tribol. Conf. 2019.

Formulated gear oils include a variety of phosphorus & sulfur extreme pressure co-additives. Their impact on ZrO<sub>2</sub> film formation is of great interest.

**Goal:** Understand the influence that ZrO<sub>2</sub>-co-additive interactions have on the tribological performance of oil-dispersed ZrO<sub>2</sub> NPs.

# 2. Methods



## Oil Formulations

ZrO<sub>2</sub> in polyalphaolefin (PAO) base oils:

- Viscosity 1 (4 cSt\*): ZrO<sub>2</sub>+PAO4
- Viscosity 2 (10 cSt): ZrO<sub>2</sub>+PAO10

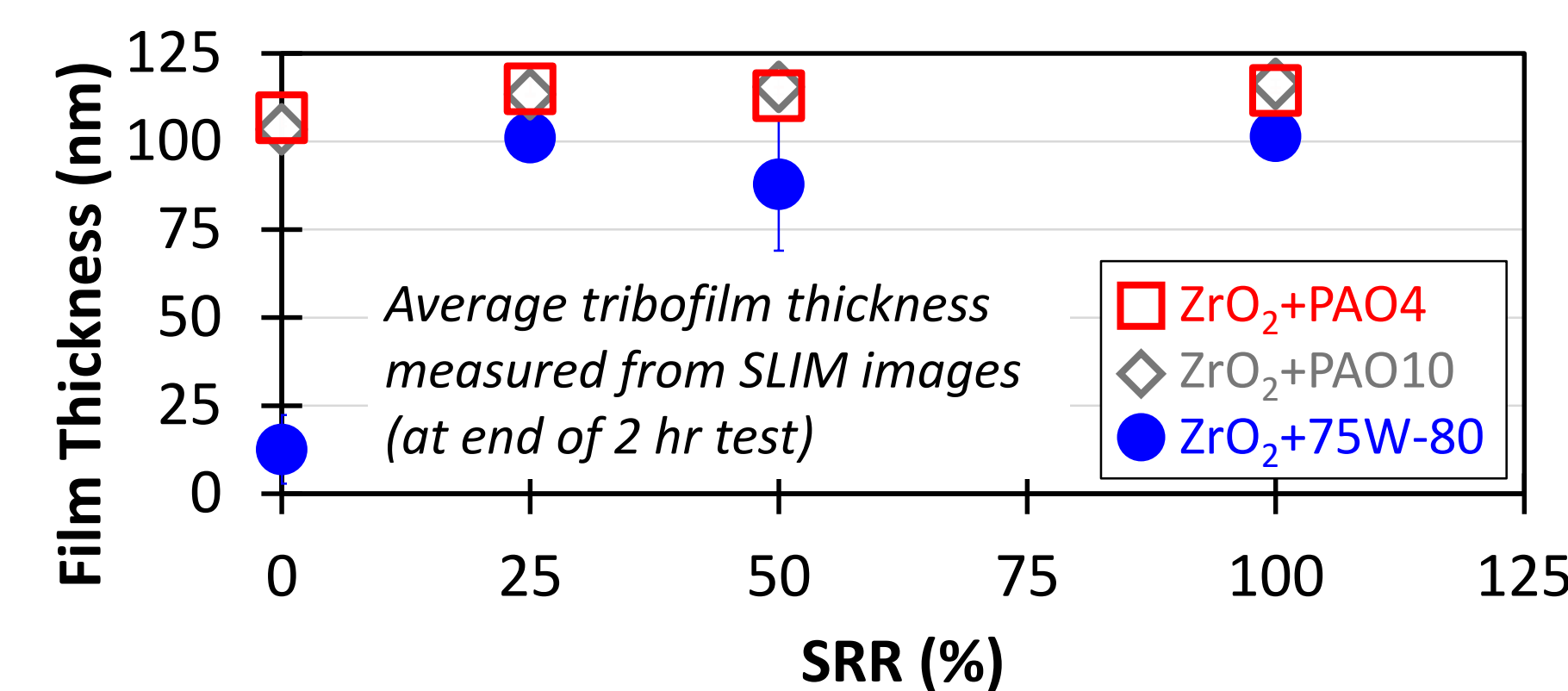
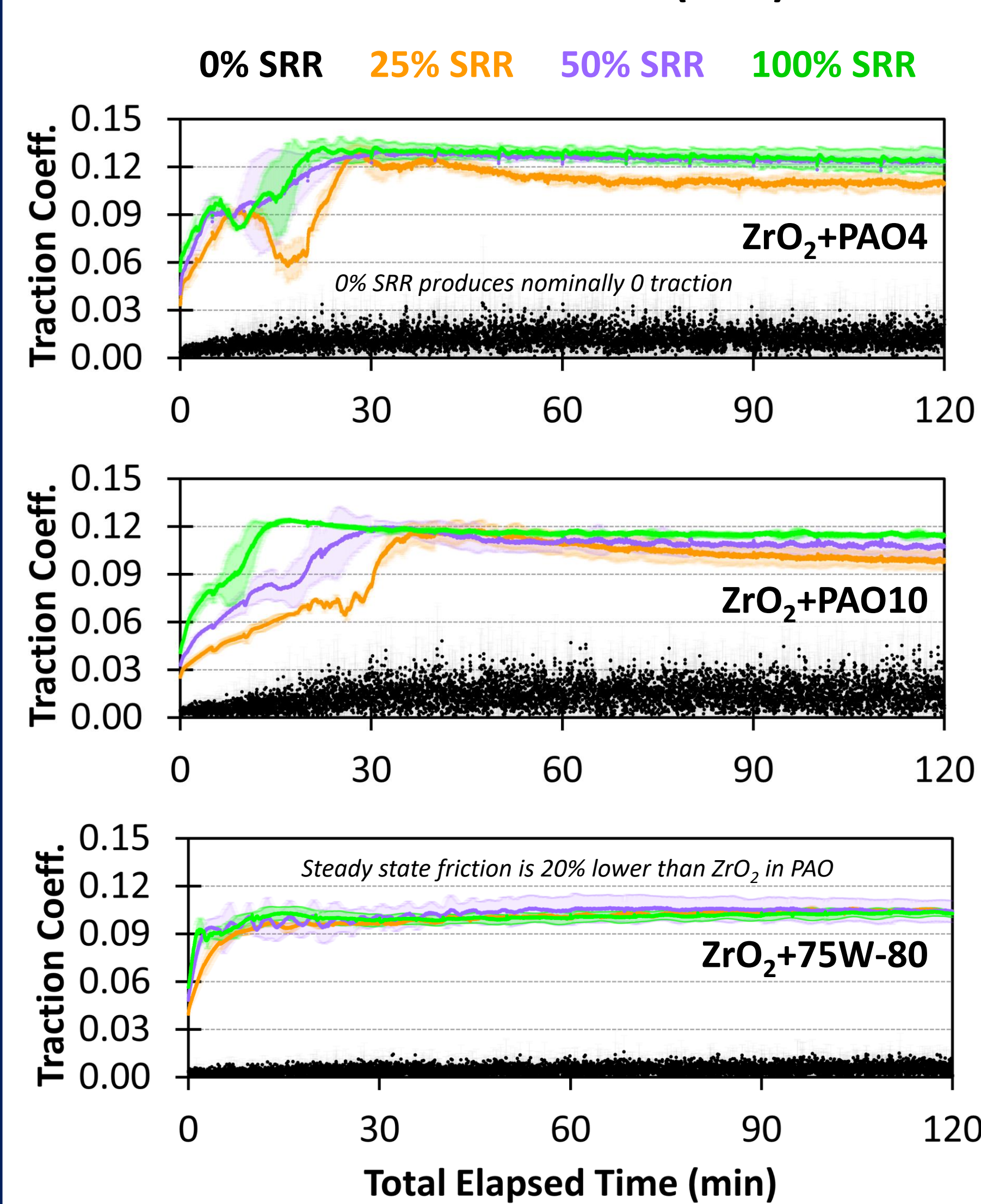
ZrO<sub>2</sub> in fully formulated SAE 75W-80 gear oil:

- P- & S-Containing (9.6 cSt): ZrO<sub>2</sub>+SAE 75W-80

\*viscosities at 100 °C

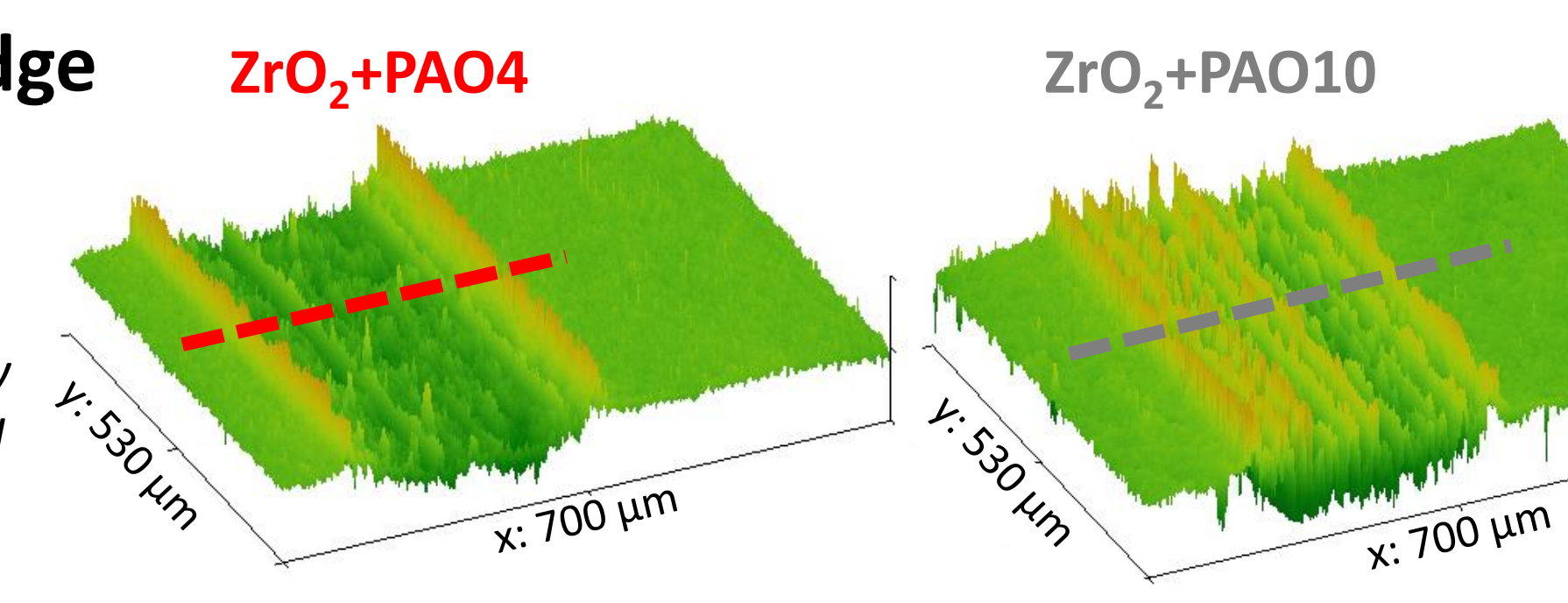
# 3. ZrO<sub>2</sub> Tribofilms + Co-Additives Form for Wide Range of Rolling/Sliding

## Tribofilm Behavior as a Function of Slide-to-Roll Ratio (SRR)



## Tribofilm Step-Edge Morphologies @ 100% SRR

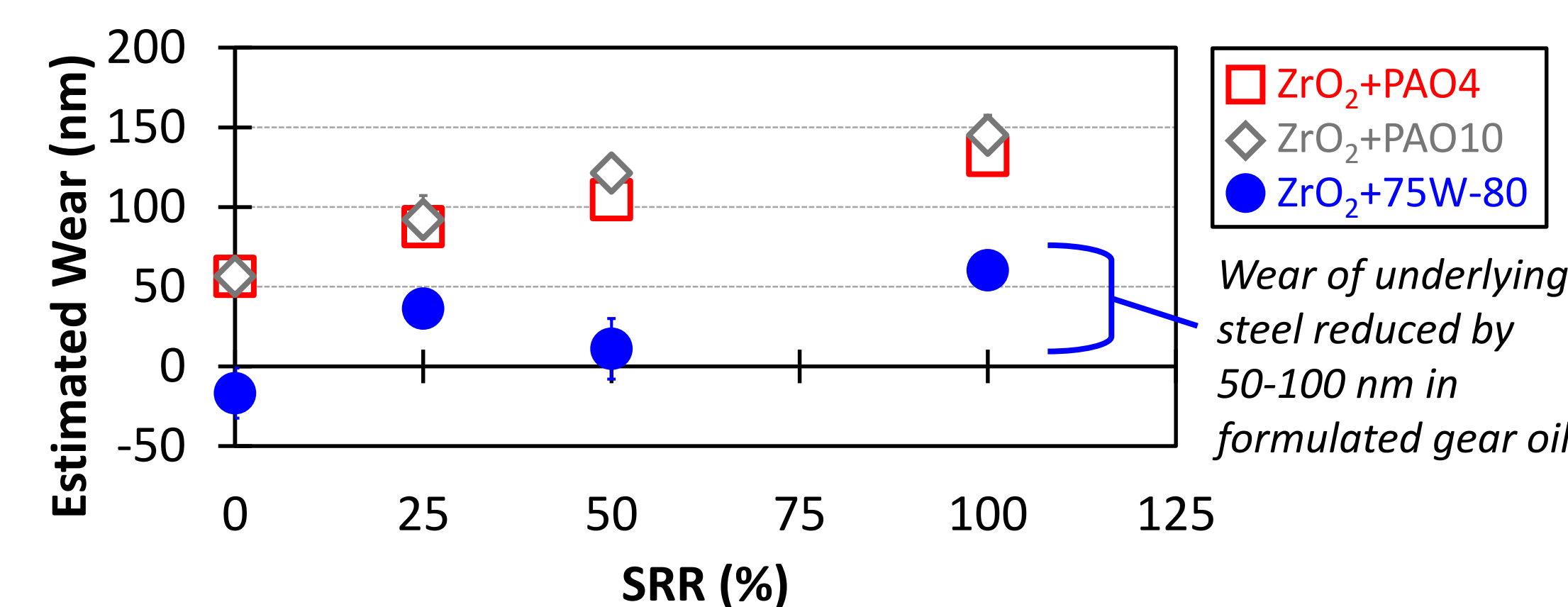
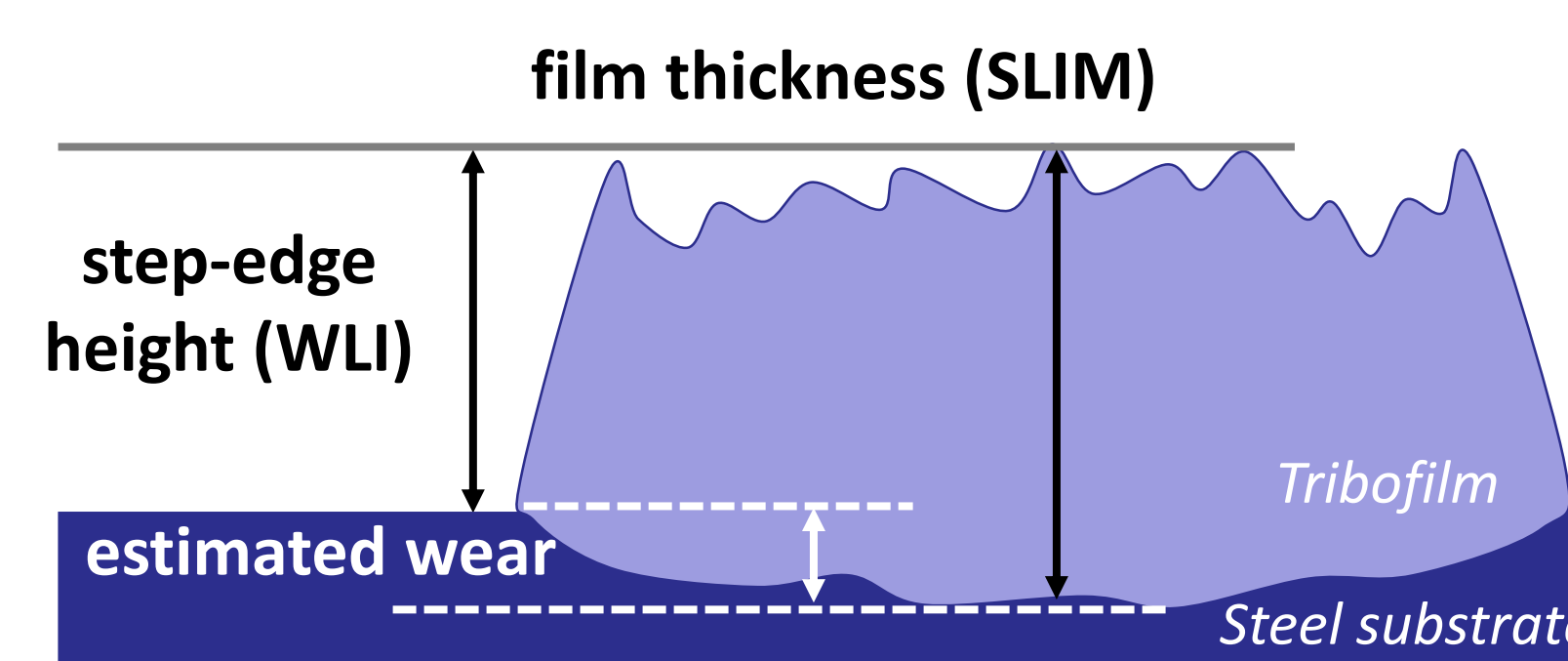
White light interferometry (WLI) images of MTM ball specimens with reflective Au/Pd coating



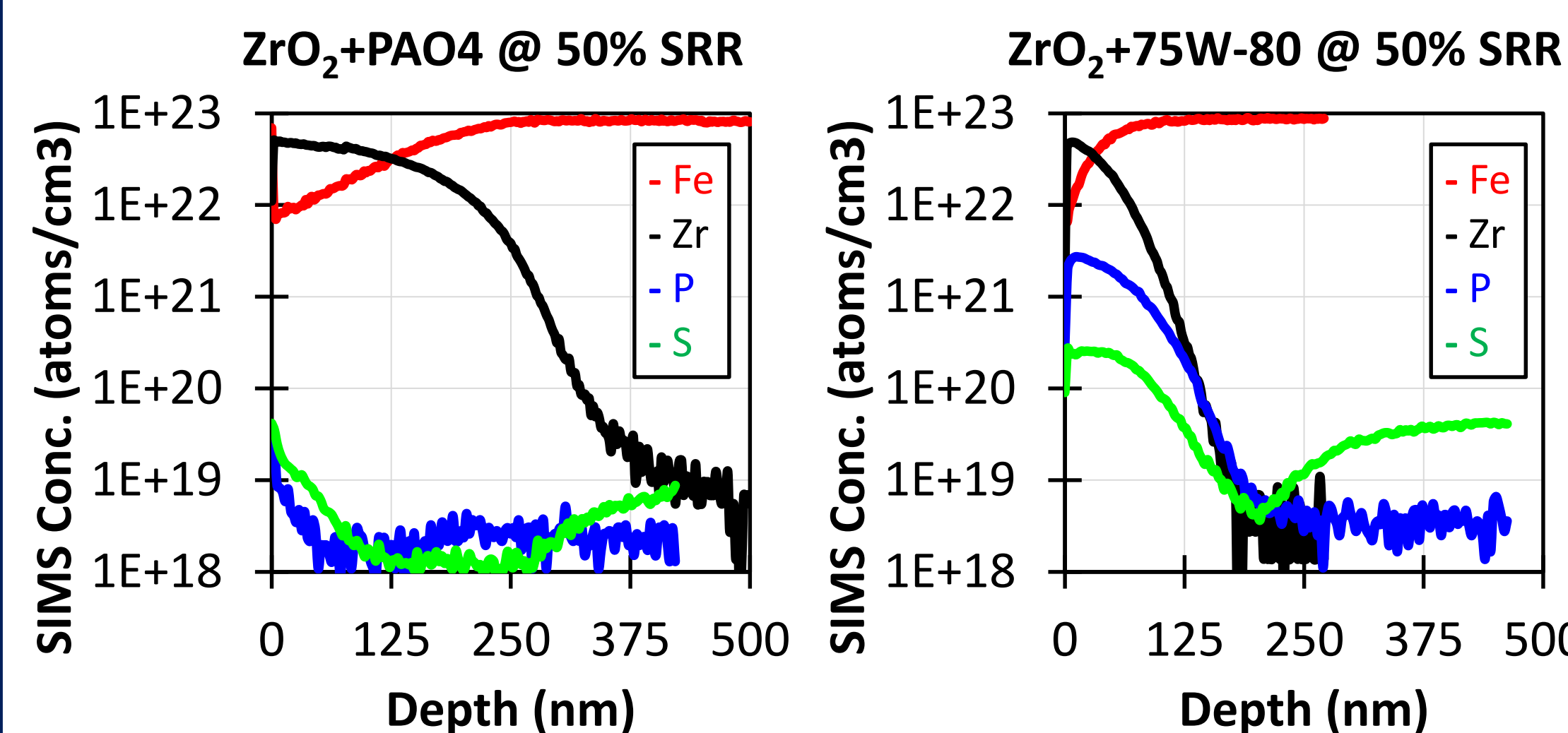
Despite consistent tribofilm thicknesses, step-edge height depends on both formulation and SRR. At higher SRRs for ZrO<sub>2</sub>+PAO, there is early adhesive wear before the ZrO<sub>2</sub> film starts to form; build-up of the ZrO<sub>2</sub> film inside the wear track prevents further damage.

When co-additives are present (ZrO<sub>2</sub>+75W-80), initial adhesive wear is prevented and the ZrO<sub>2</sub> film builds up on the unworn surface.

# 4. Co-Additives Are Incorporated Into ZrO<sub>2</sub> Tribofilms



Improvement in antiwear behavior is attributed to the presence of P & S containing co-additives.



## Secondary Ion Mass Spectrometry (SIMS) Depth Profiling

Orders of magnitude more P & S are present in a tribofilm formed in 75W-80 vs PAO. This P & S content correlates with Zr as a function of depth, indicating co-additives incorporate into the tribofilm structure.

ZrO<sub>2</sub> tribofilms, in (behavior)

ZrO<sub>2</sub> tribofilms, friction 2

P- & S-co-additives: a) reduced, b) incorporated

Manuscript in Zirconium Dioxide

# 6.

This research... Capabilities... Systems... Technol... DE-SC-0... Additional... University of... University of... member su...