Microanalysis of Third Body Material After Dry Sliding on Cold Sprayed Al and Al-Al_2O_3

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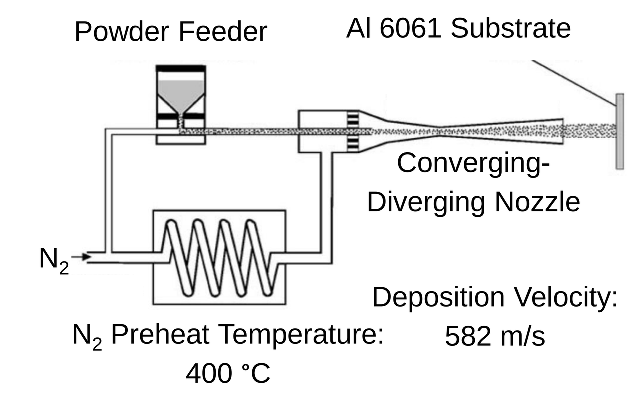
INTRODUCTION

Particle-reinforced aluminum matrix composites (Al-MMCs) generally exhibit lower wear rates and more stable friction than their un-reinforced matrix materials [1]. Cold spray is a popular consolidation route for Al-Al_2O_3, allowing for its application as a coating for corrosion and tribological protection. Previous work by the authors has found that **22 wt.% of angular Al_2O_3** particles leads to significantly lower wear rates and greater friction stability compared to unreinforced **pure Al** cold sprayed coatings (see figures below) [2,3] .

Characterization of the material present in the wear tracks is challenging. Third body layers may be only a few microns thick, and contain metastable / nanocrystalline / amorphous material. In this study, TEM methods were used to characterize the third body material of **pure Al** and **Al- 22 wt.% Al_2O_3** cold spray coatings. In doing so, a mechanistic explanation of the contrasting dry sliding wear behavior of the two samples can be derived by describing the material transformations occurring at the sliding interface, which are dependent on the presence of Al_2O_3 particles.

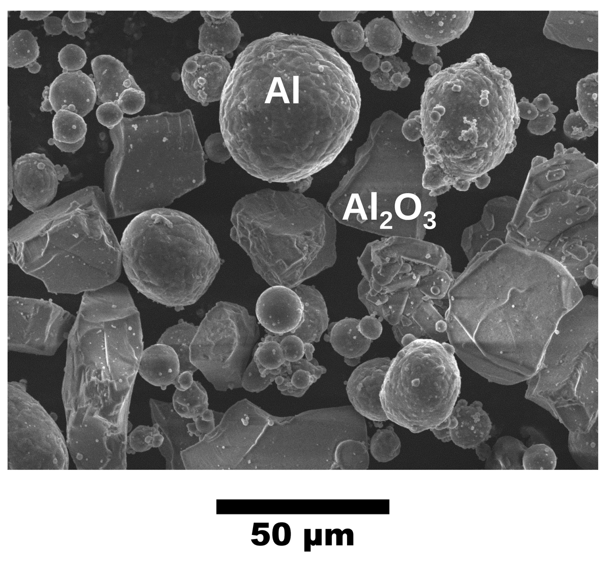
COLD SPRAY DEPOSITION OF Al AND Al-Al_2O_3

Process Schematic



Coating deposition occurs through plastic deformation upon impact.

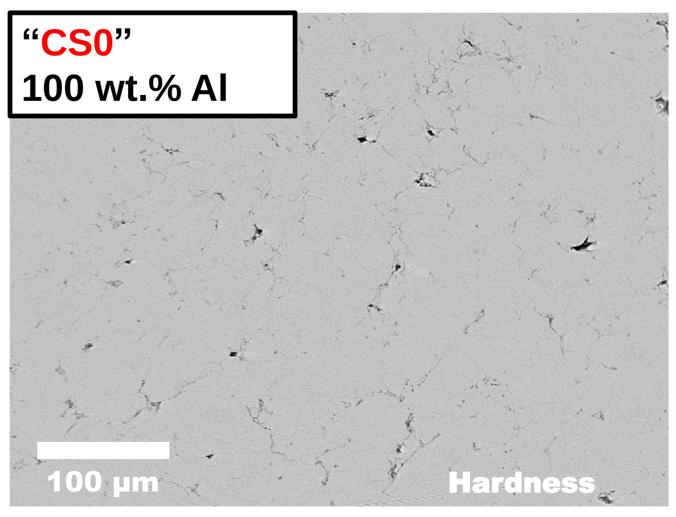
Feedstock Powders



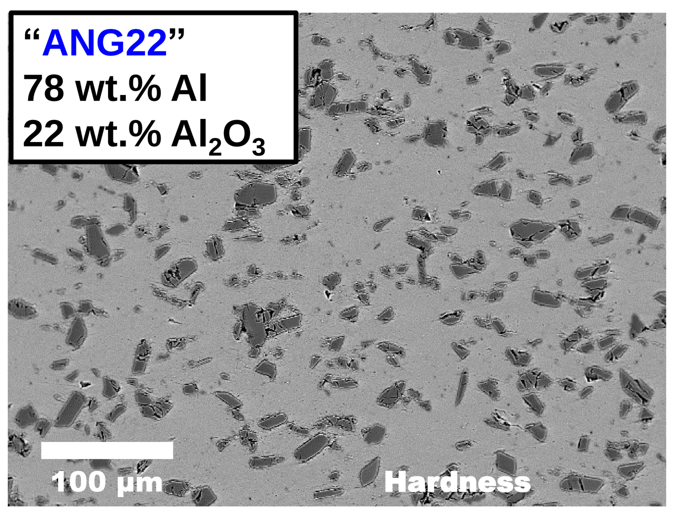
CS0 feedstock: 100% spherical Al

ANG22 feedstock: 50 wt.% spherical Al 50 wt.% angular Al_2O_3 (admixture)

MATERIALS STUDIED: Al AND Al-Al_2O_3

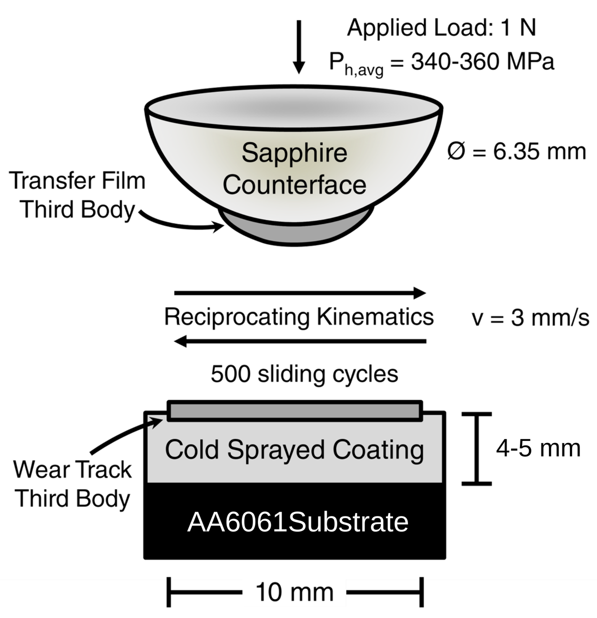


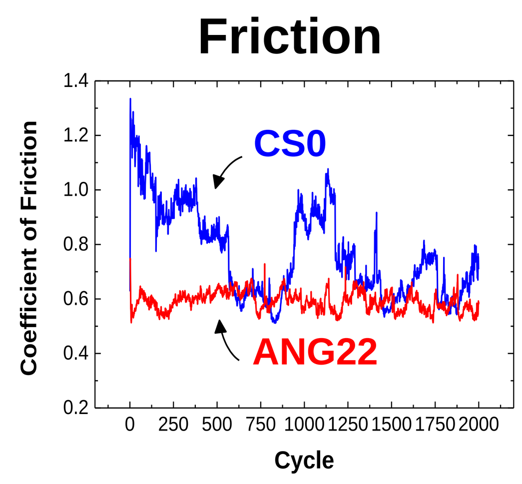
The pure Al coating consolidated into a dense microstructure with <2% porosity.

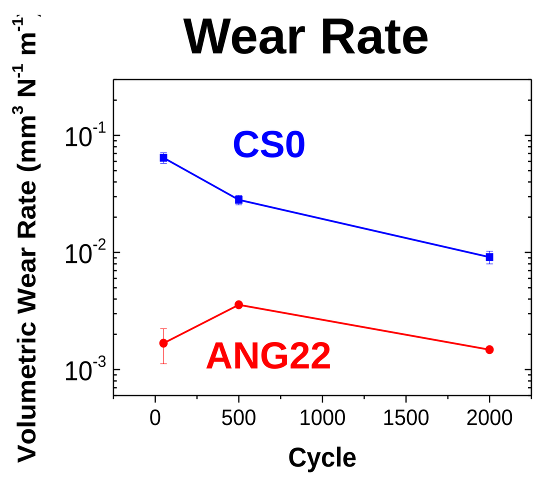


A proportion of the Al_2O_3 particles were recovered to form a uniform Al-Al_2O_3 microstructure.

DRY SLIDING WEAR EXPERIMENTS





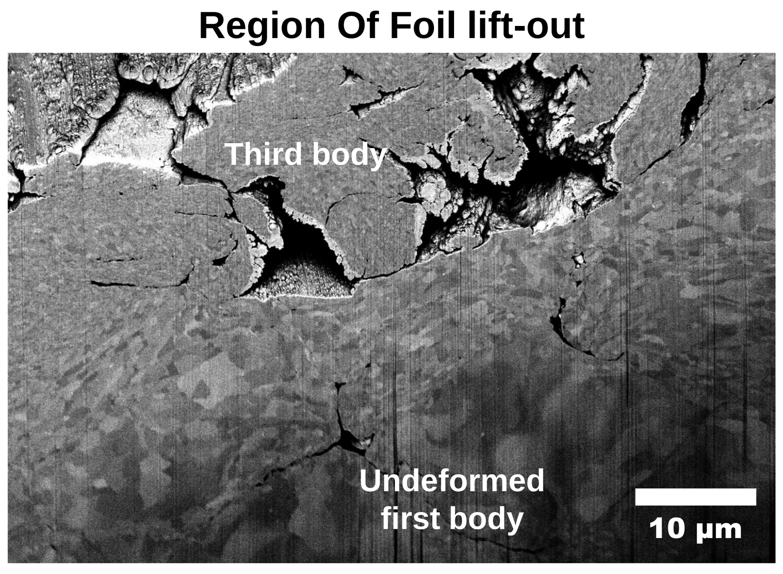


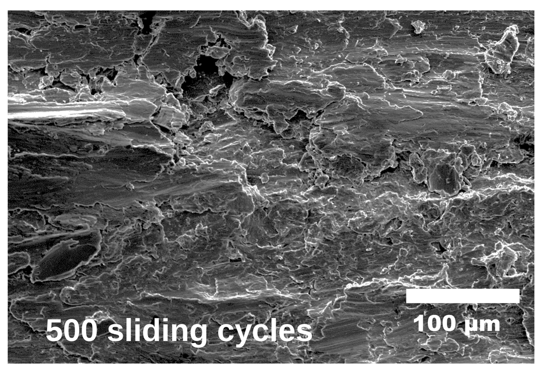
The presence of 22 wt.% Al_2O_3 particles is associated with stable friction and greatly lowered wear rates.

MICROANALYSIS: BRIGHT FIELD TEM AND ELEMENTAL MAPPING

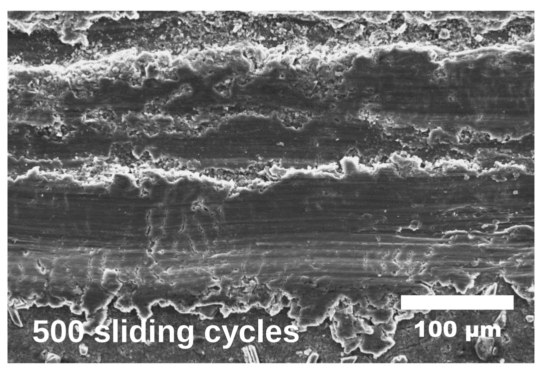
CS0: 100 wt.% Al

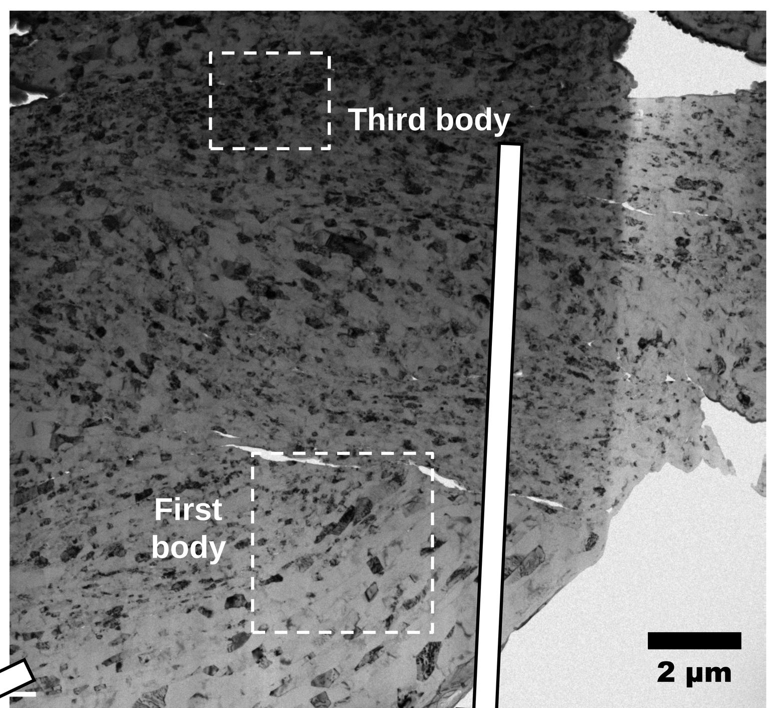
Region Of Foil lift-out



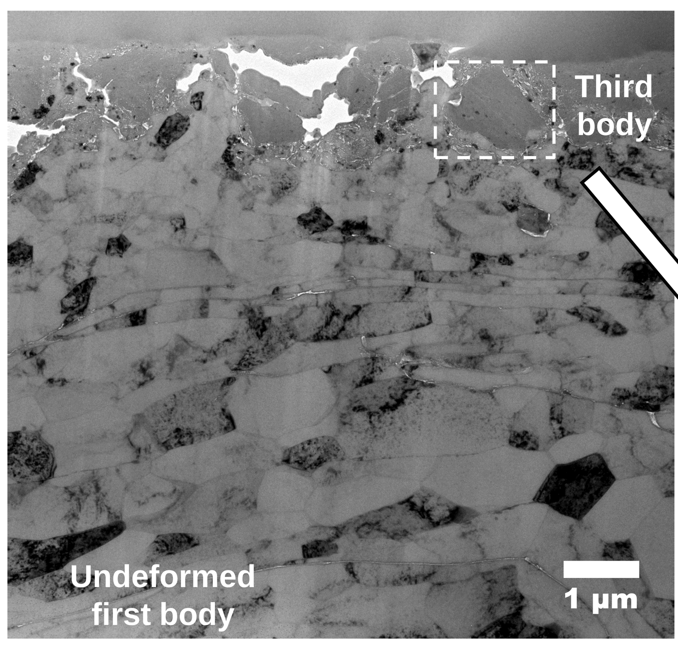


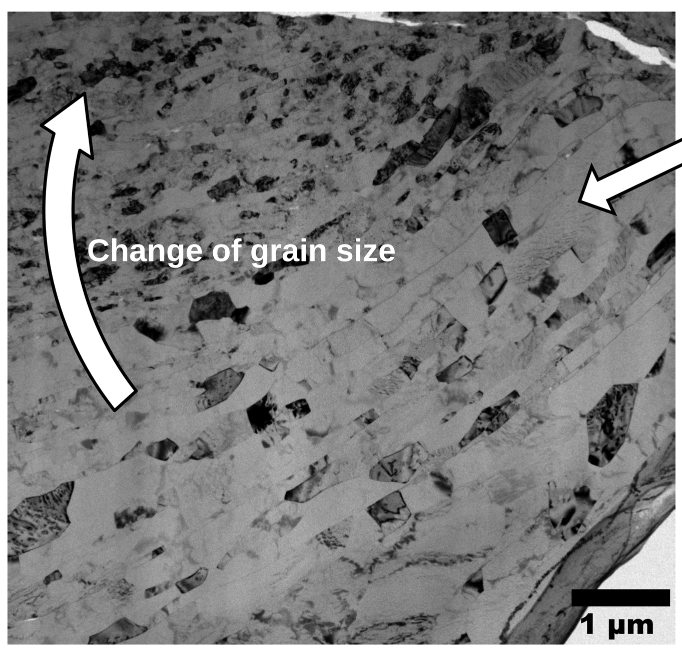
Surface analysis of wear tracks reveals:
- **CS0** shows evidence of adhesion and smearing
- **ANG22** forms smooth, coherent tribofilms



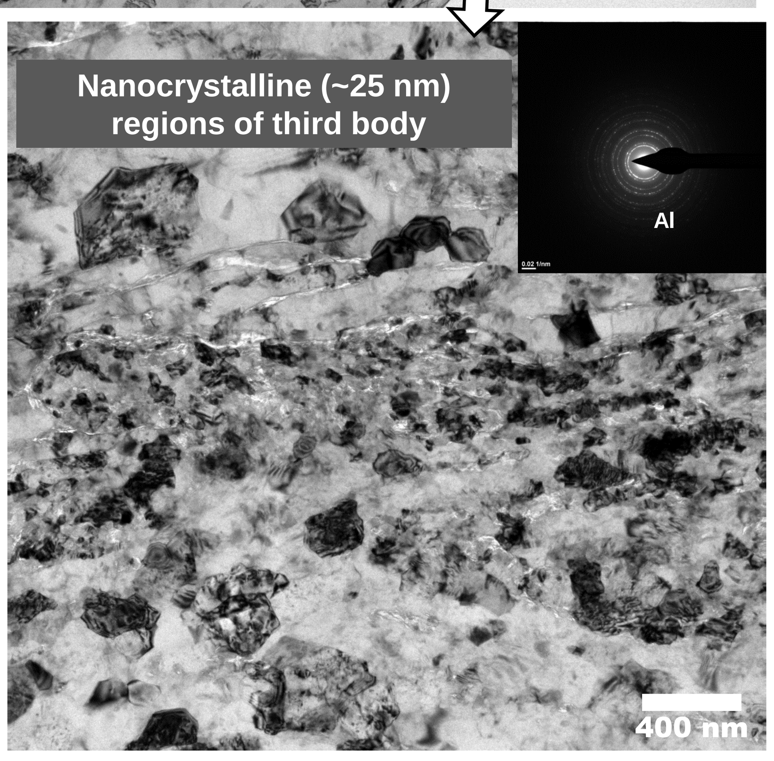


Low magnification TEM reveals:
- **CS0** : subsurface deformation runs very deep, making gradients of grain size
- **ANG22** : sharp transition from "large" grained Al to third body



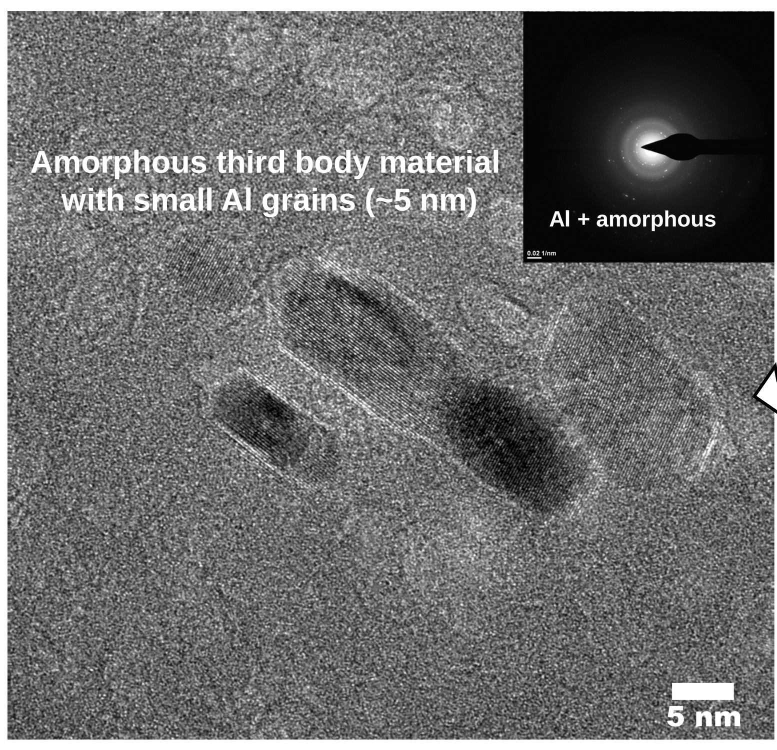


Grain size gradient: transition from third body to first body



High magnification TEM of third bodies reveals:
- **CS0** Mixture of grain sizes down to nanocrystalline
- **ANG22** primarily amorphous material with very small small Al grains mixed in

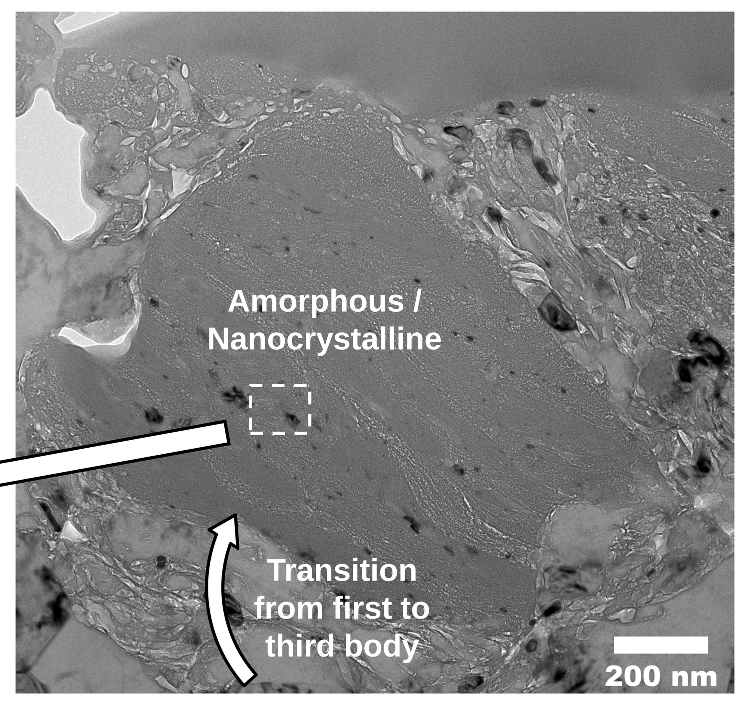
Nanoindentation hardness of third bodies:
- **CS0** ~1.5 GPa
- **ANG22** ~3.8 GPa



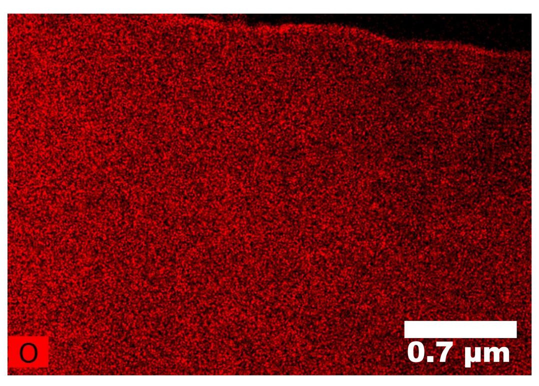
ANG22: Al-22 wt.% Al_2O_3

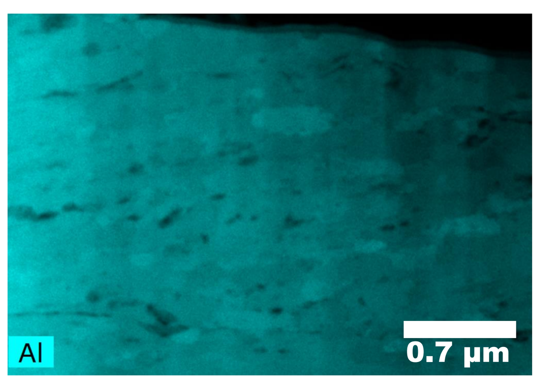
Region Of Foil lift-out

High magnification analysis of third body

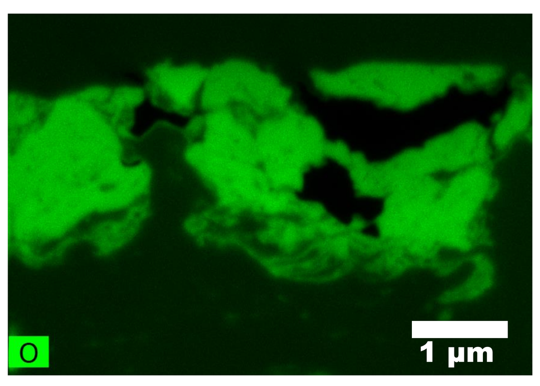


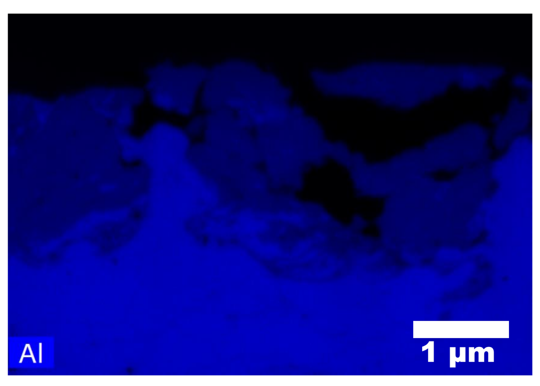
Relatively sharp transition from first to third body





EDS mapping reveals:
- **CS0** : Moderately elevated oxygen levels in third body
- **ANG22** Third body oxygen levels nearly as high as α-Al_2O_3





ACKNOWLEDGEMENTS AND REFERENCES

[1] G.W. Stachowiak and A.W. Batchelor, Engineering Tribology (Elsevier, Amsterdam, 2005).
[2] J.M. Shockley, H. Strauss, R.R. Chromik, N. Brodusch, R. Gauvin, E. Irissou, J.-G. Legoux / Surface and Coatings Technology 215 (2013) pp. 350-356.
[3] J.M. Shockley, S. Descartes, E. Irissou, J.-G. Legoux, R. R. Chromik / Tribology Letters 54 (2014) pp. 191–206.
[4] S. Descartes, C. Desrayaud, E. F. Rauch / Materials Science and Engineering A 528 (2011) pp. 3666–3675.

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CONCLUSIONS

FIB lift-out and TEM have revealed details of the microstructural changes occurring in third body material after dry sliding wear of cold sprayed **Al** and **Al-Al_2O_3**. The presence of 22 wt.% Al_2O_3 particles led to the formation of a largely amorphous, heavily oxidized third body layer. This was much harder than the nanocrystalline third body material of the pure Al and protected the underlying material from damage.