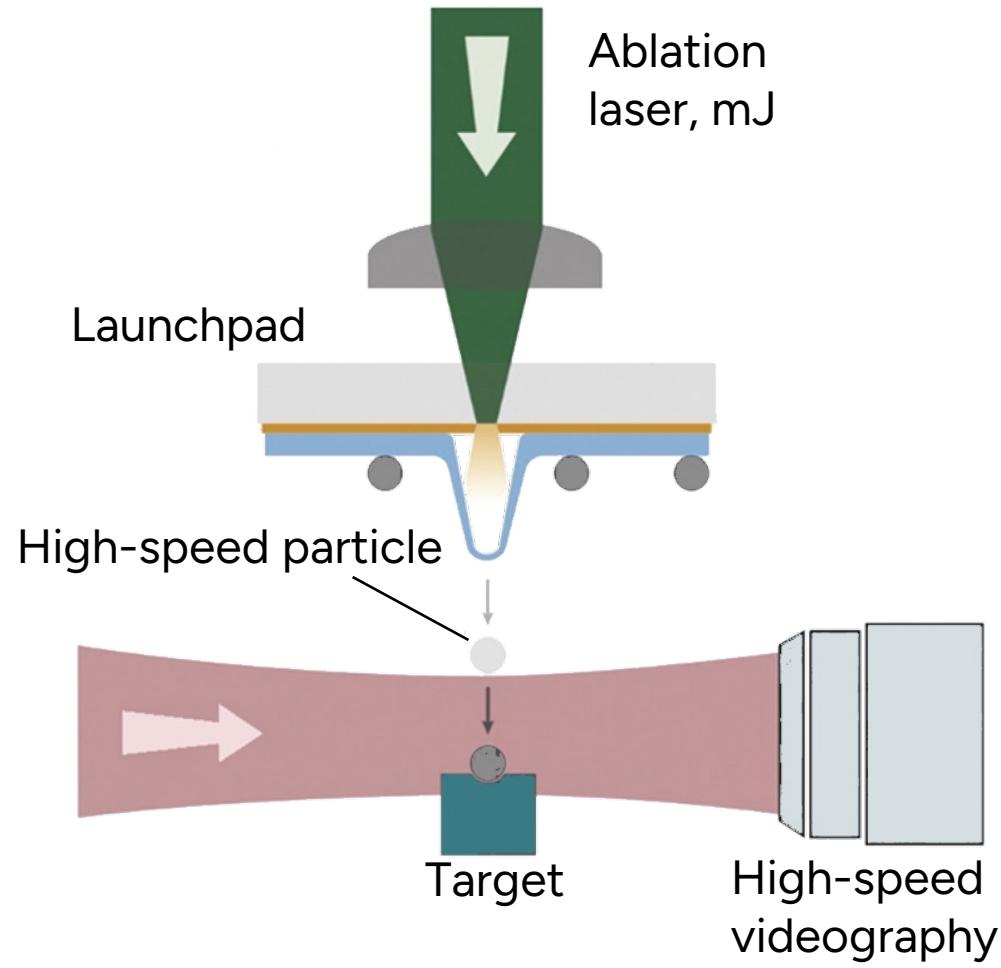
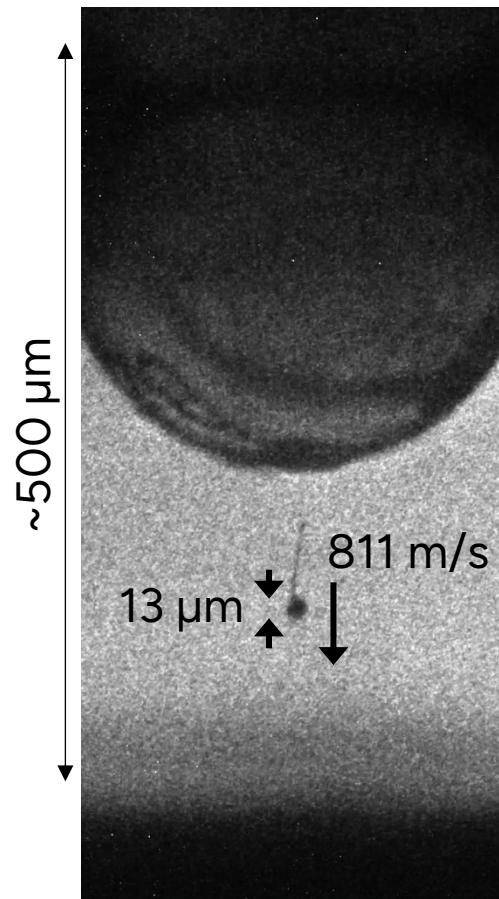


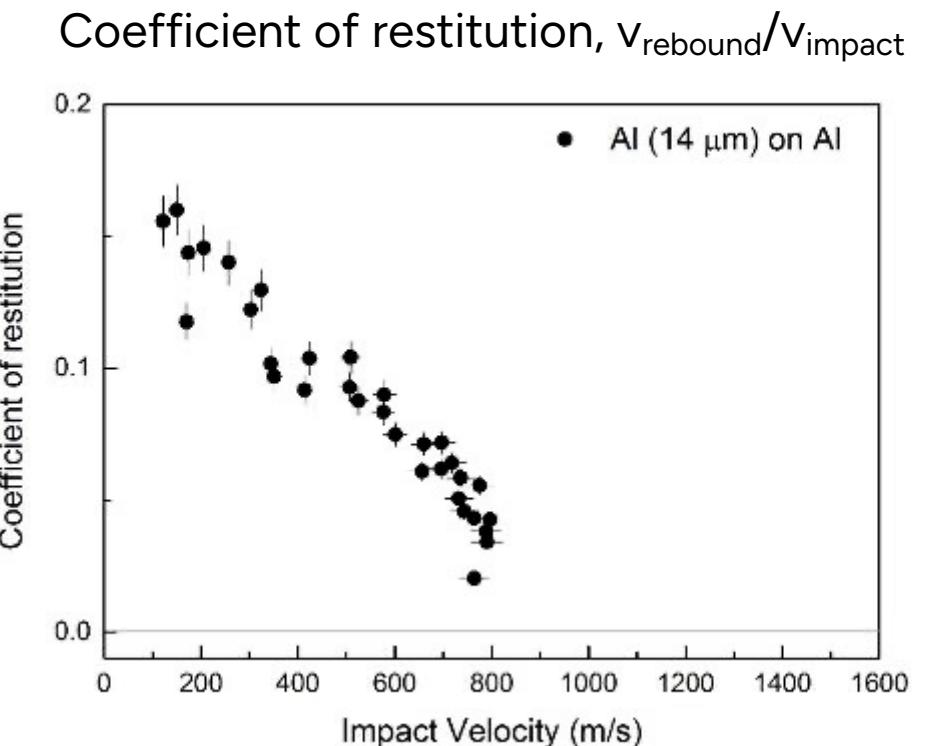
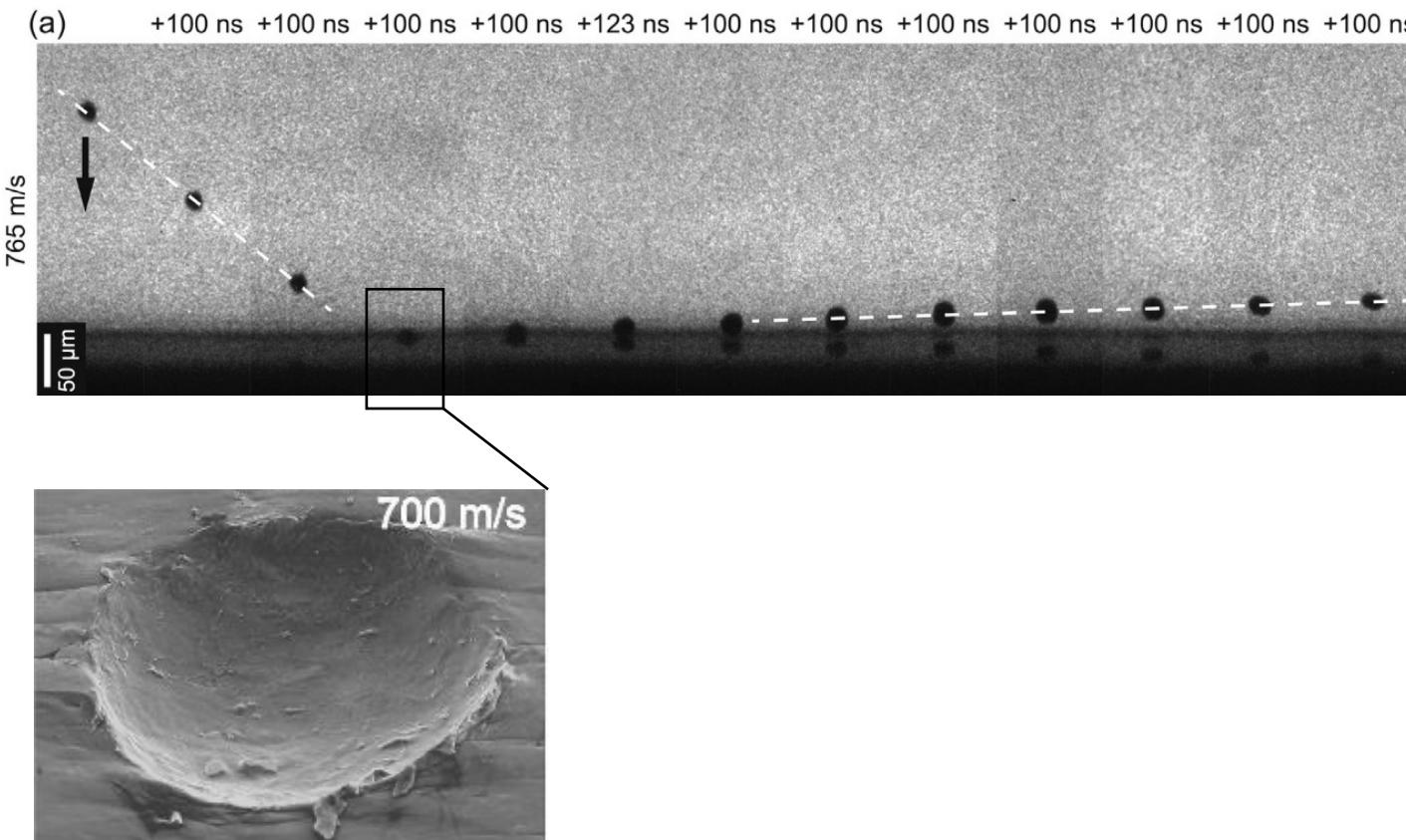
Many-particle impact bonding with quantitative single-particle experiments

Alain Reiser, Christopher Schuh

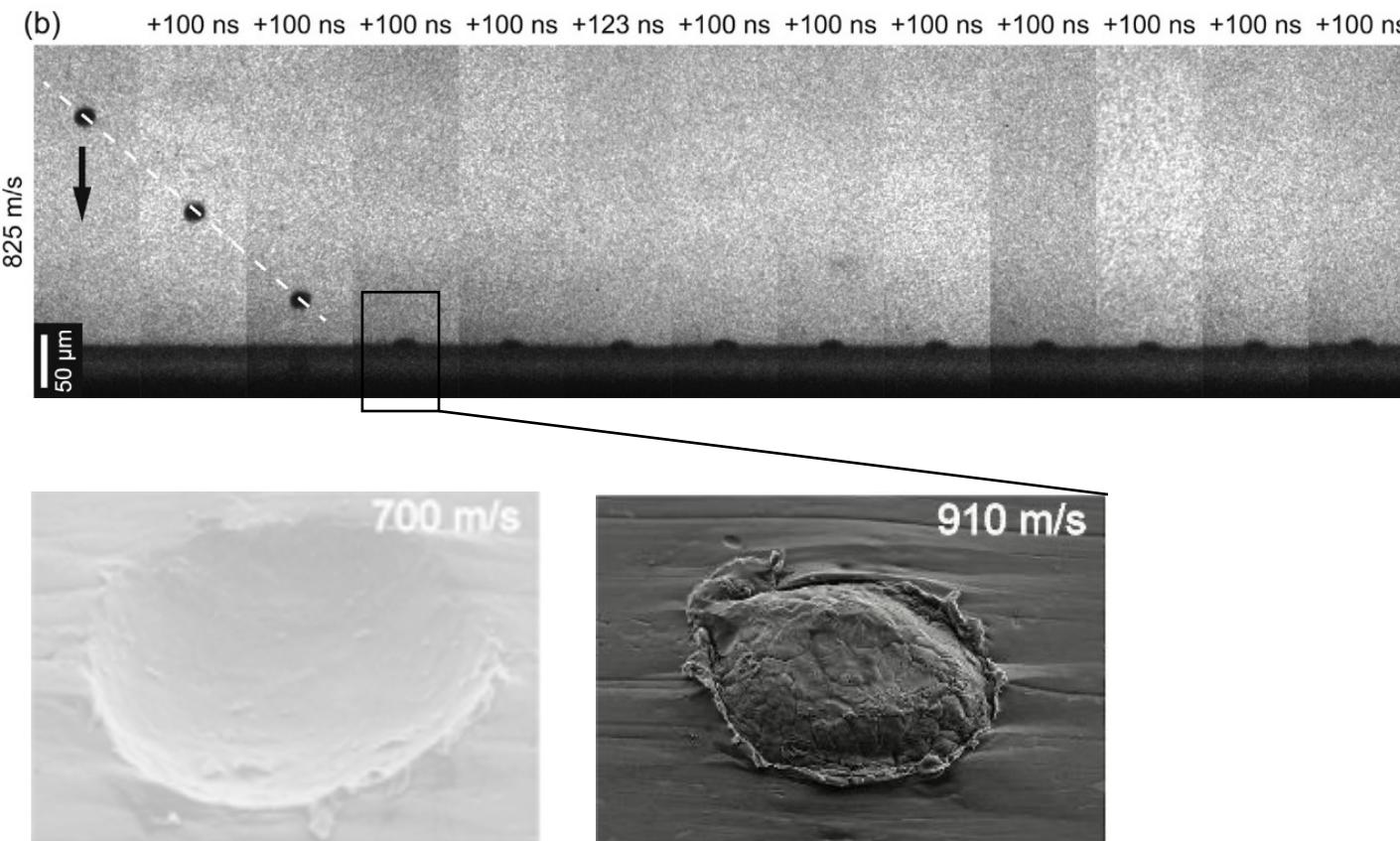
Laser-induced particle impact testing (LIPIT)



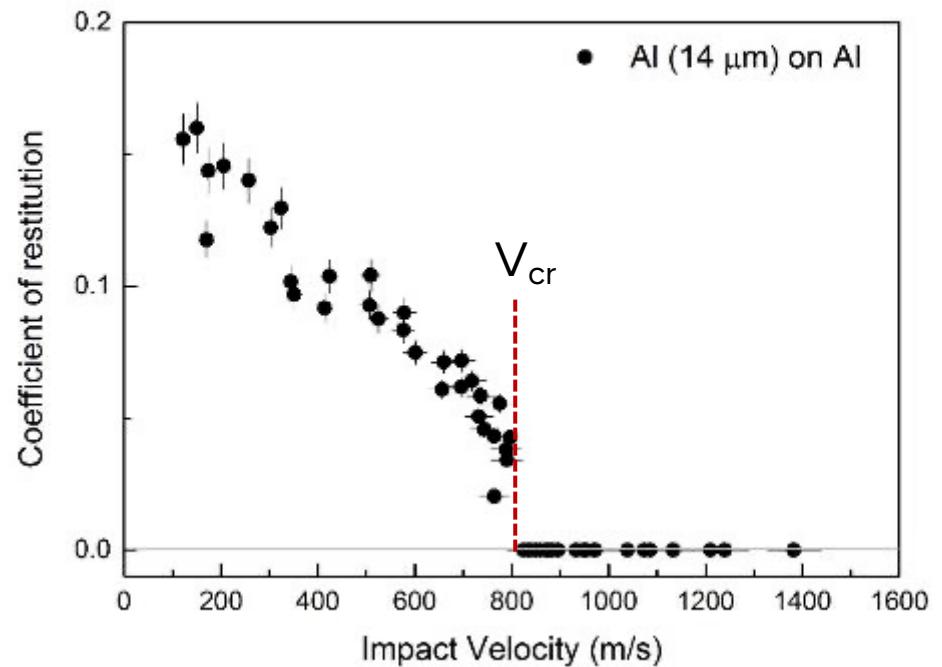
Example: from particle rebound to adhesion



Example: from particle rebound to adhesion

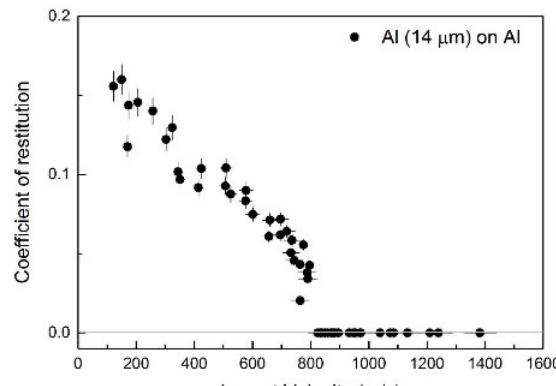


Coefficient of restitution, $v_{\text{rebound}}/v_{\text{impact}}$



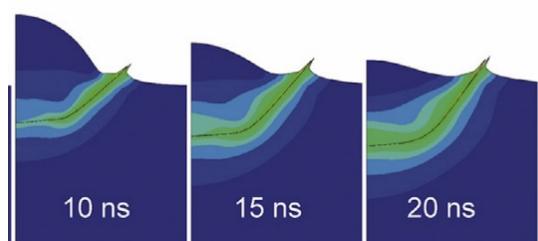
LIPIT: fundamentals of cold spray

Bonding



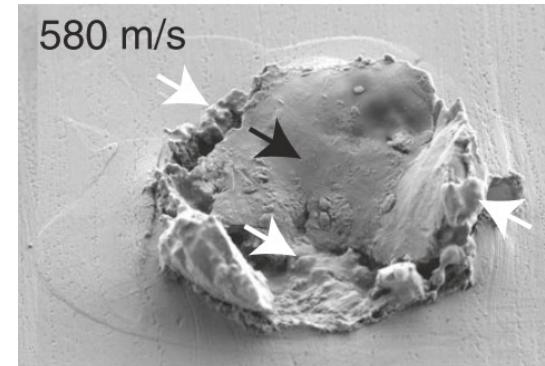
Hassani-Gangaraj et al. *Scripta Materialia* 145 (2018) 9–13.

without thermal softening

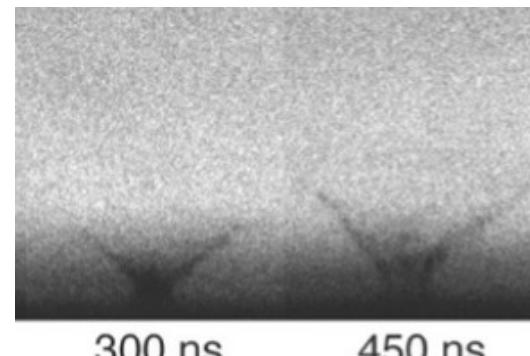


Hassani-Gangaraj, M. et al. (2018). *Acta Materialia*, 158, 430–439.

Melting and Erosion

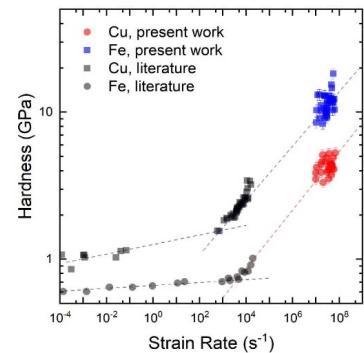
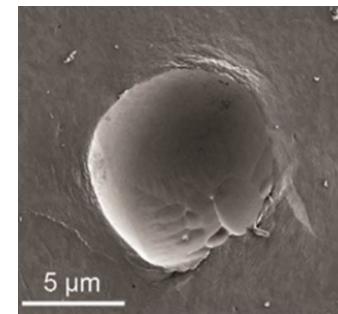


Hassani-Gangaraj, M. et al. (2018). *Nature Communications*, 9(1), 5077.



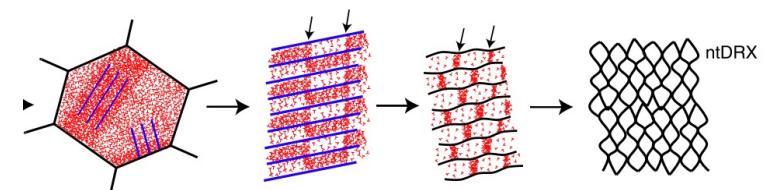
Lienhard, J. et al. (2022). *Surface and Coatings Technology*, 432.

Dynamic materials properties and better materials models



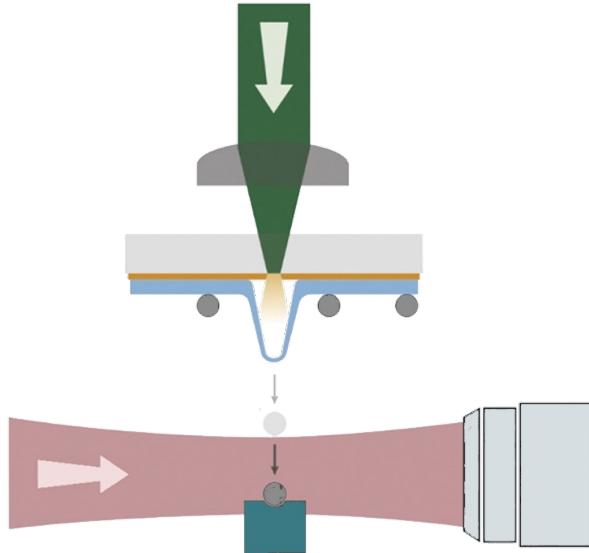
Hassani, M., Veysset, D., Nelson, K. A., & Schuh, C. A. (2020). *Scripta Materialia*, 177, 198–202.

Microstructure evolution



Tiamiyu, A. A., Pang, E. L., Chen, X., LeBeau, J. M., Nelson, K. A., & Schuh, C. A., *Nat Mater*, 2 (2022).

The gap



1

?

gazillion

Number of particles

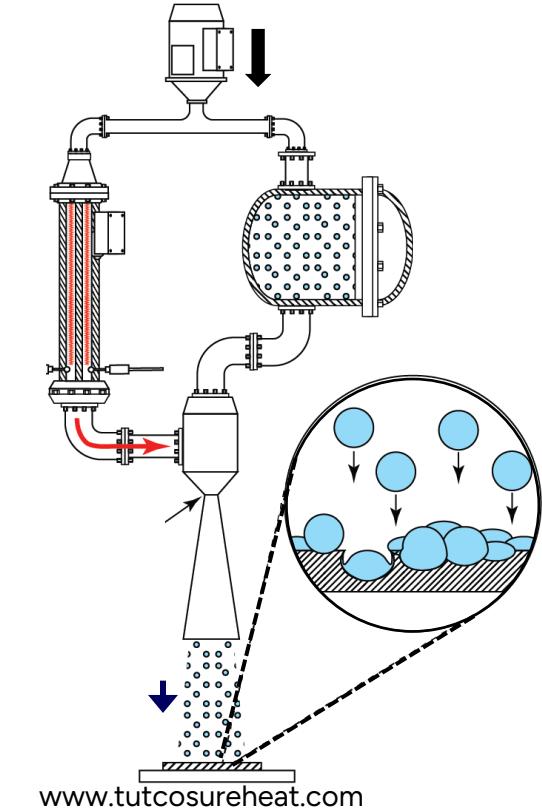
Multi-particle interactions:

- Bonding
- Pore formation
- Strain hardening
- Dynamic Recrystallisation
- Erosion
- Tamping
- ...

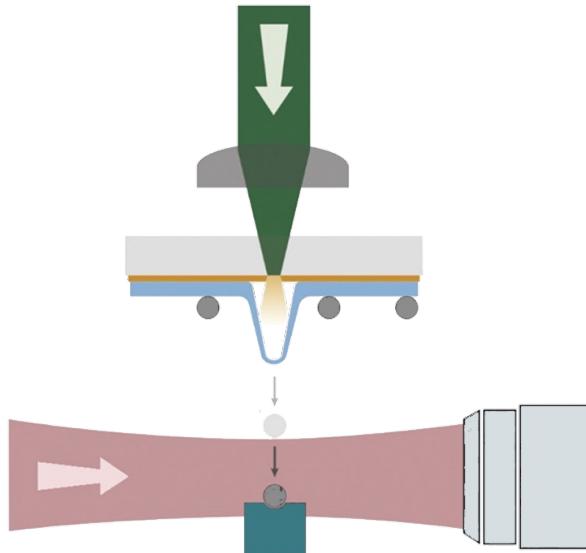
Our goal

Experimental simulation with knowledge of every particle's impact parameters:

- Kinetic energy
- Size



The gap



1

Multi-particle interactions:

- Bonding
- Pore formation
- Strain hardening
- Dynamic Recrystallisation
- Erosion
- Tamping
- ...

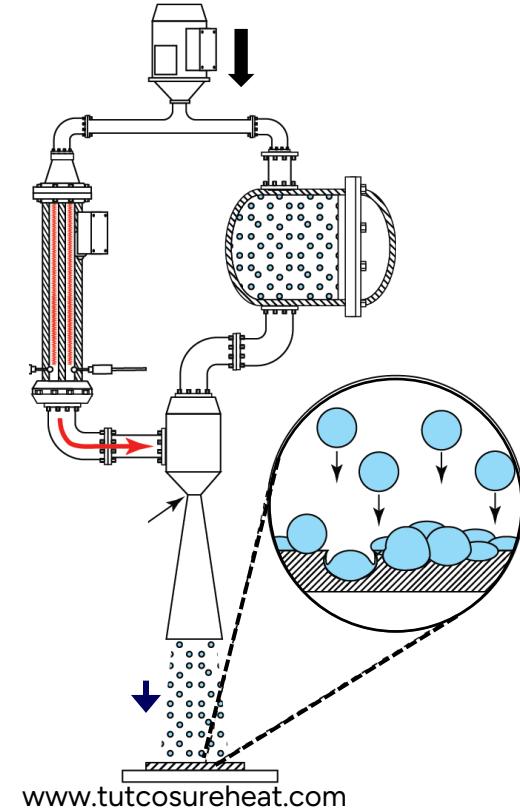
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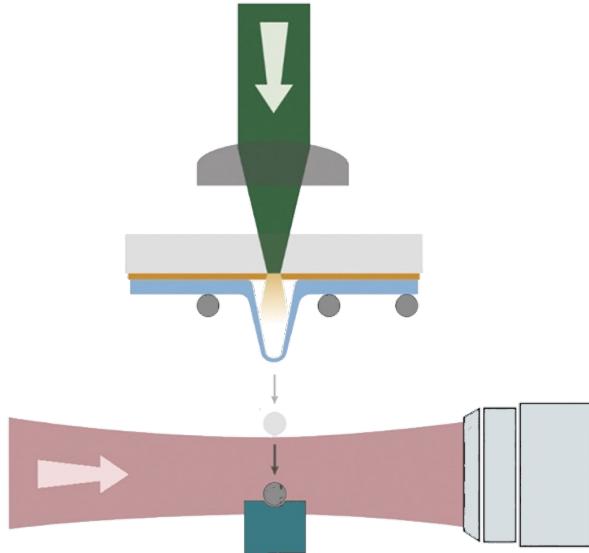
?

Number of particles



gazillion

The gap



1

Multi-particle interactions:

- Bonding
- Pore formation
- Strain hardening
- Dynamic Recrystallisation
- Erosion
- Tamping
- ...

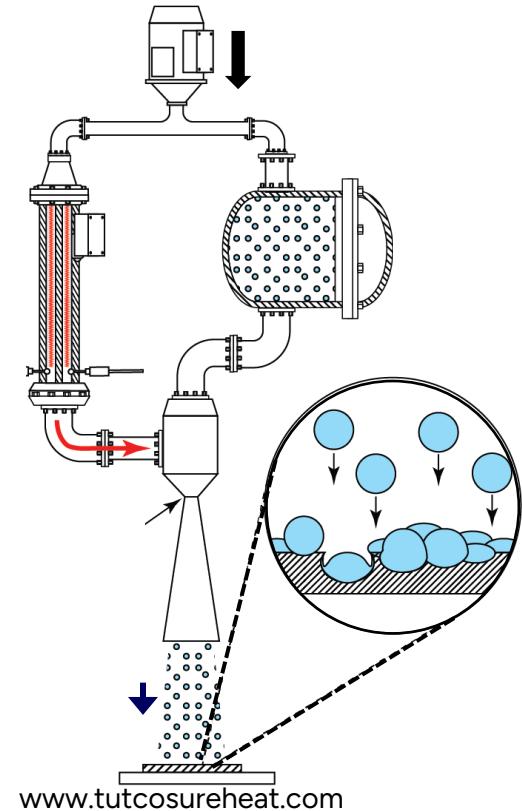
Our goal

Experimental simulation with knowledge of every particle's impact parameters:

- Kinetic energy
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?

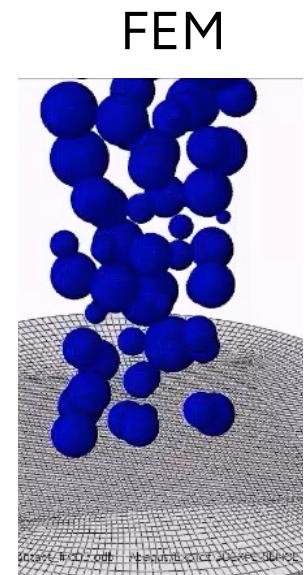
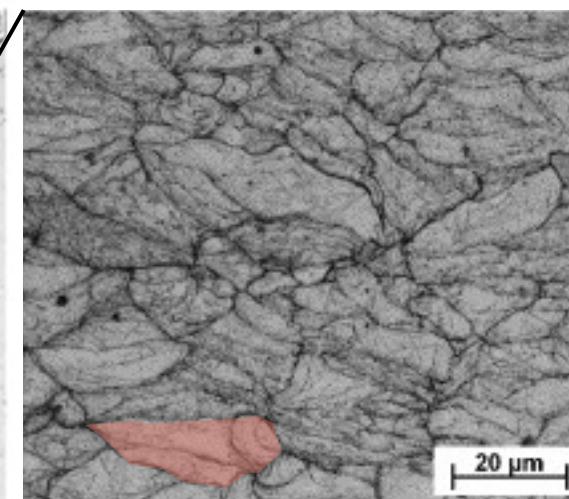
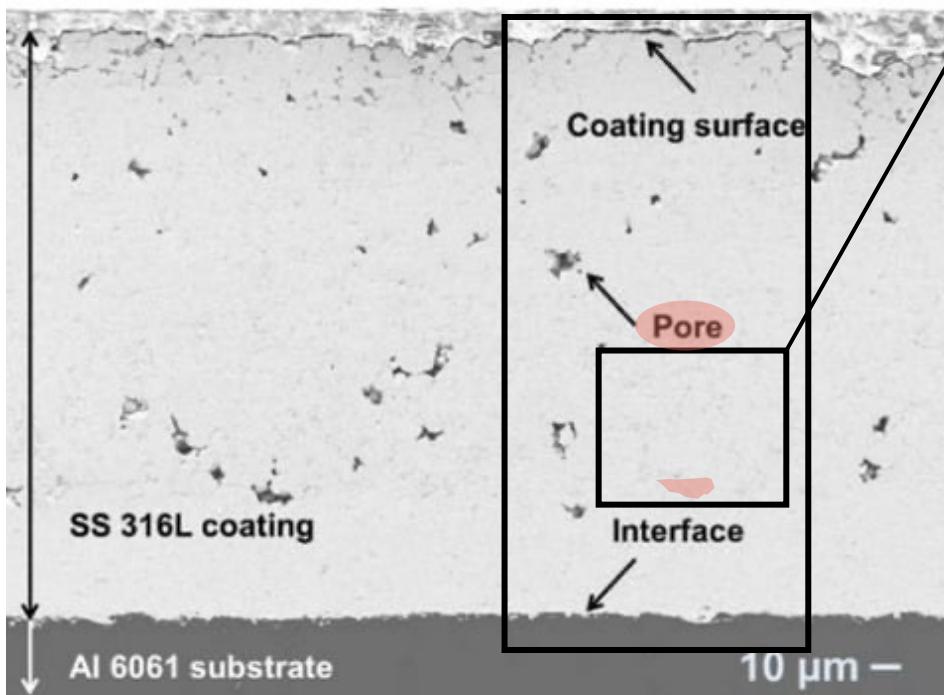
Number of particles



gazillion

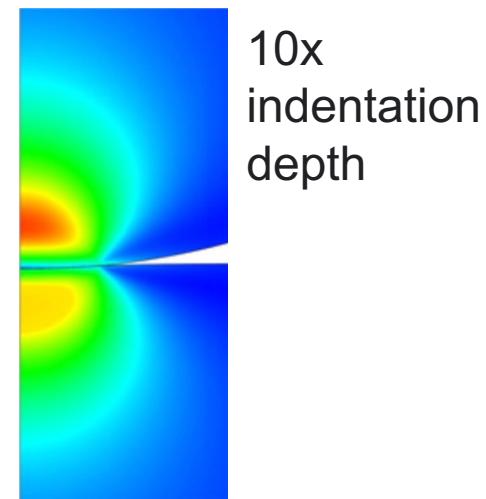
Experimental coating simulation: system size?

What is a representative volume?



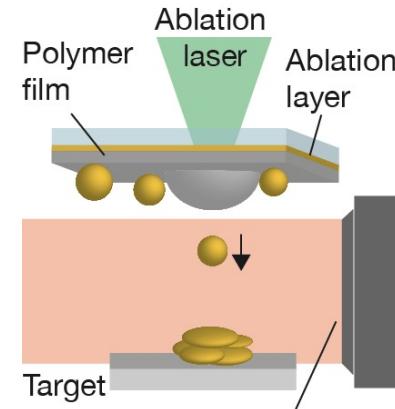
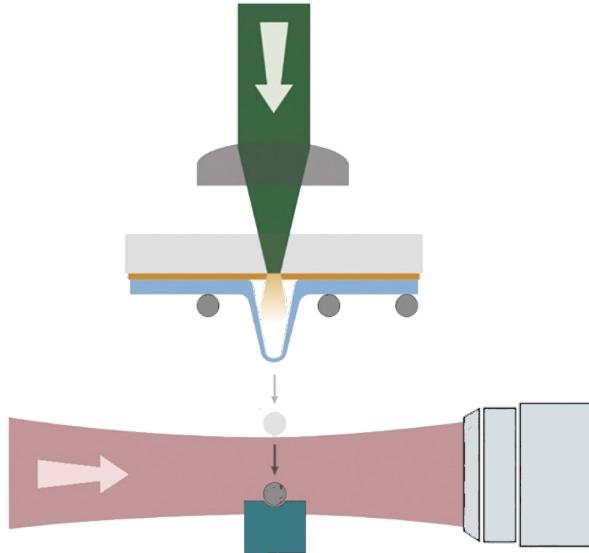
E. Liu *et al.*, Surface and Coatings Tech. (2020)

100 particles



~10 particles

Many-particle LIPIT



Our goal

Experimental simulation with knowledge of every particle's impact parameters:

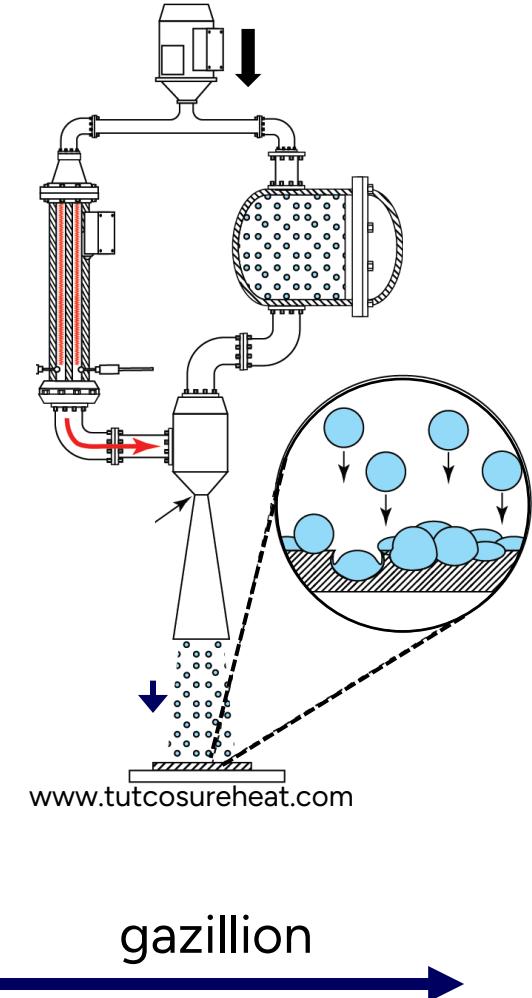
- Kinetic energy
- Size

1

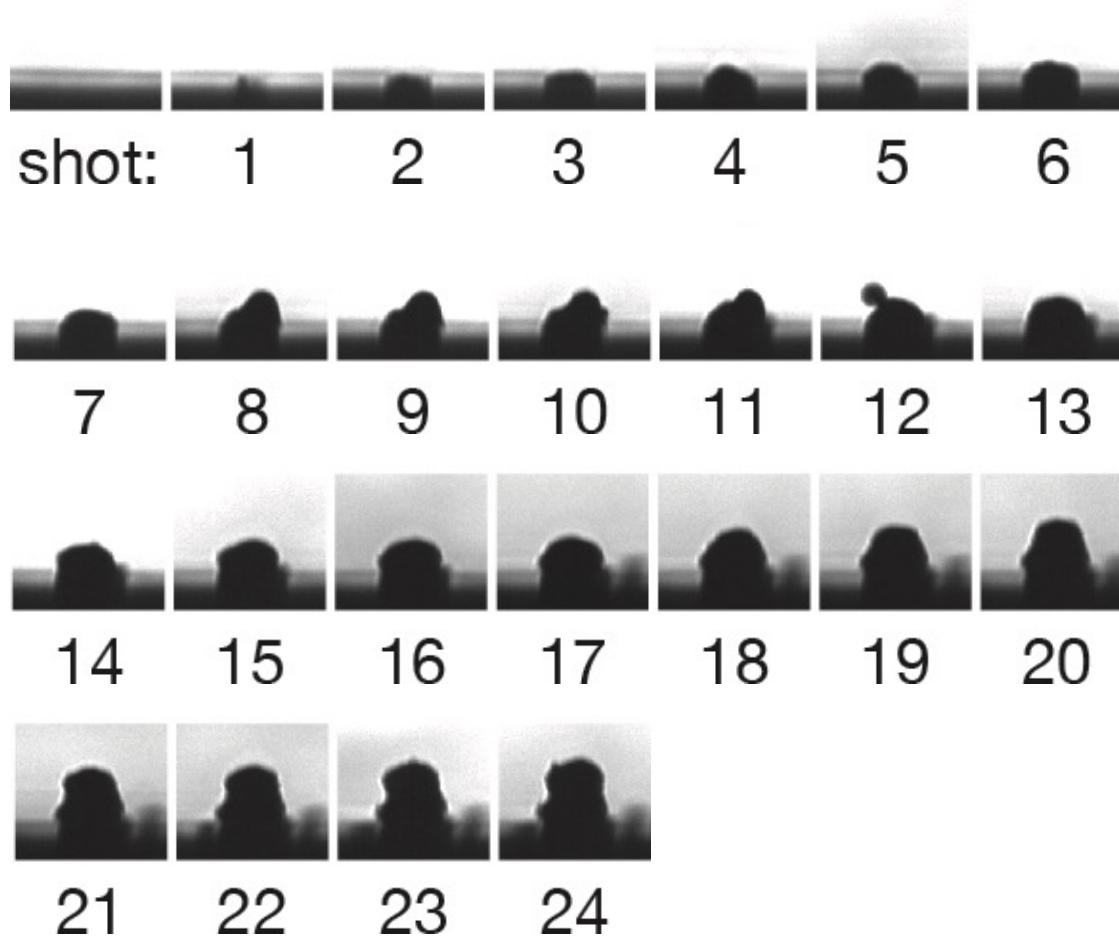
~100 particles

gazillion

Number of particles



Many-particle deposition by LIPIT

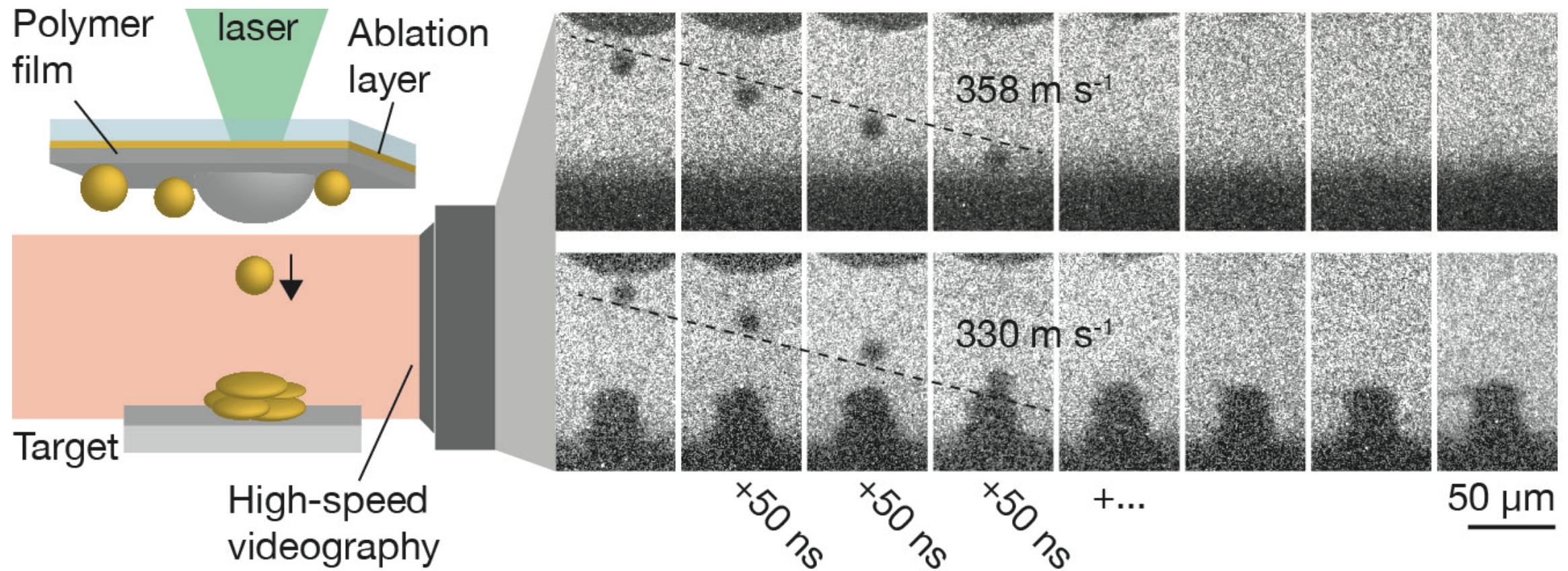


24 Au particles, 10-20 μm



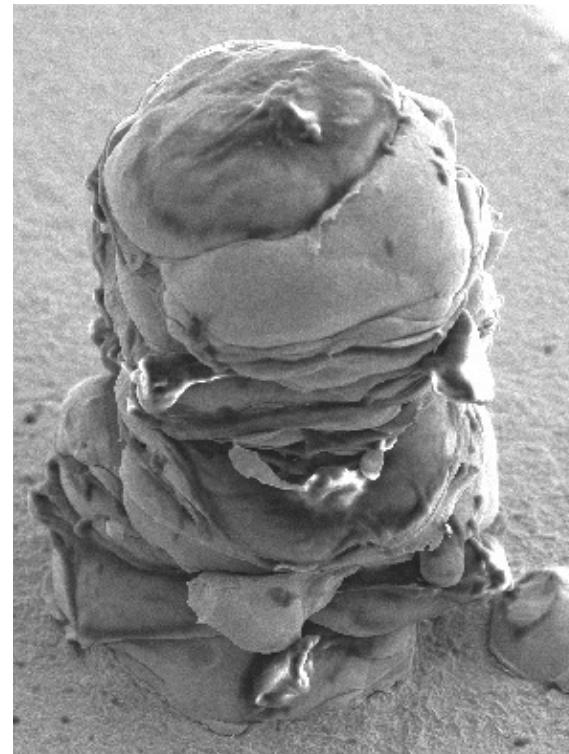
20 μm

Full LIPIIT accuracy: Quantitative, single-particle data

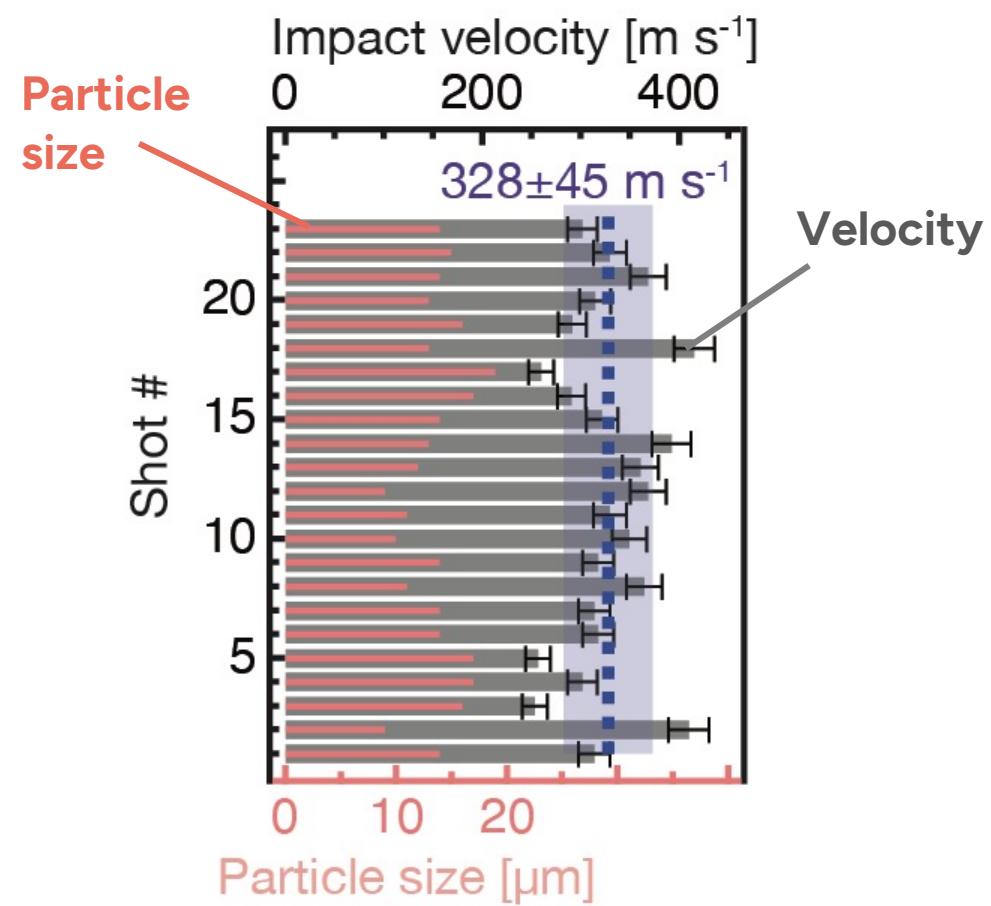


Full LIPIIT accuracy: Quantitative, single-particle data

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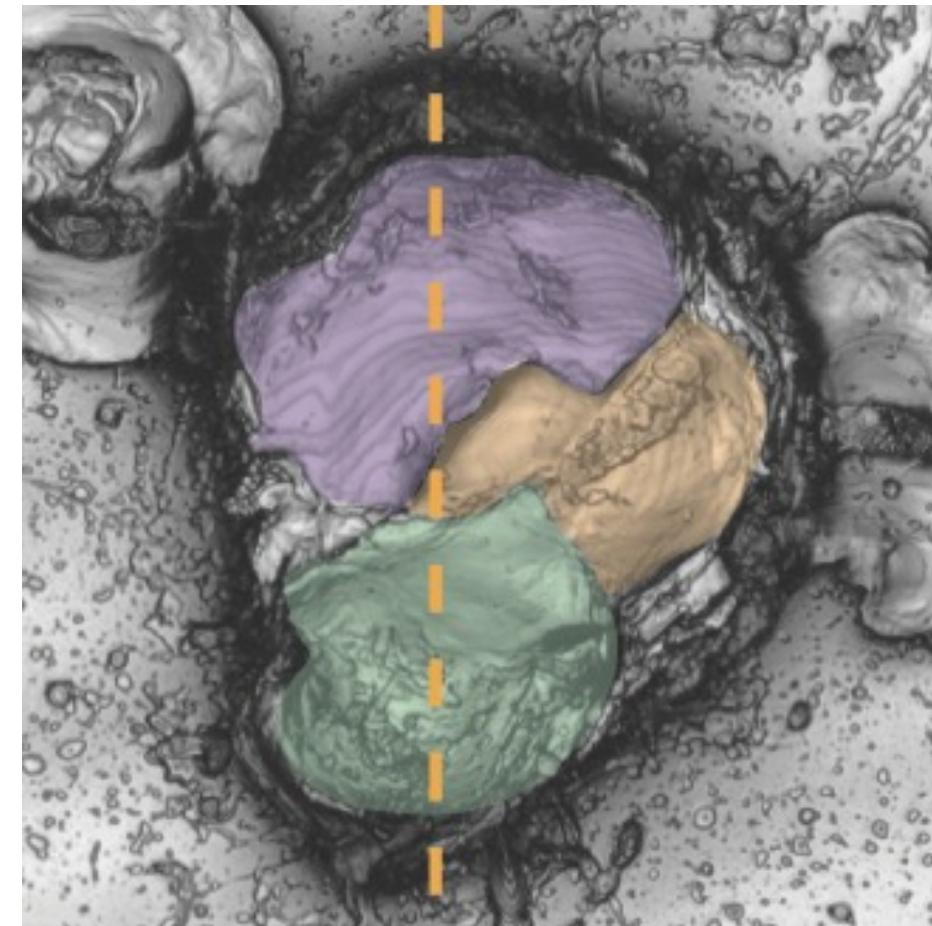
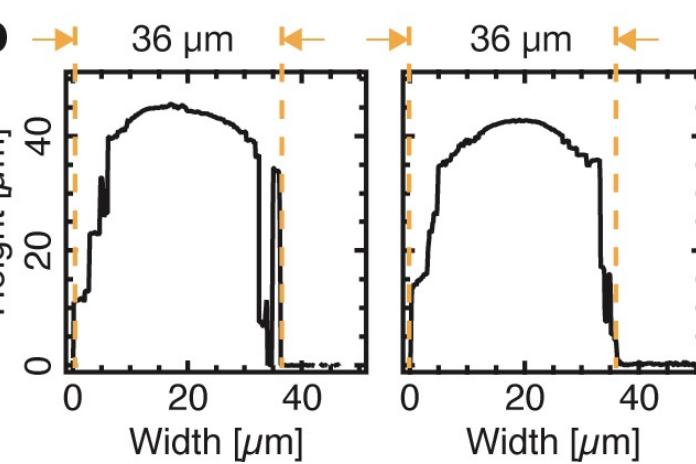
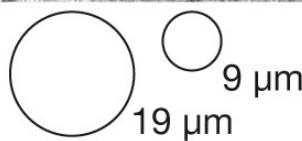
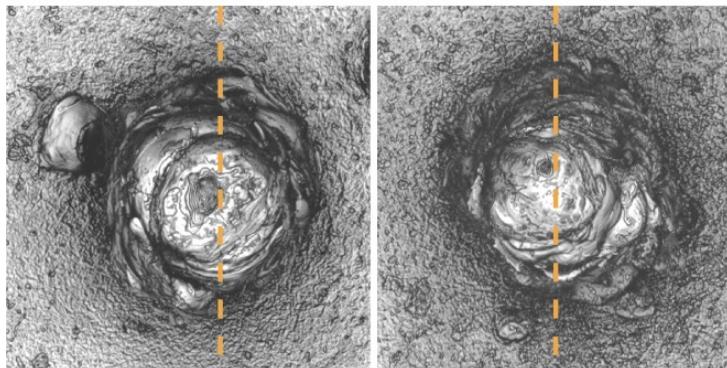


20 μm

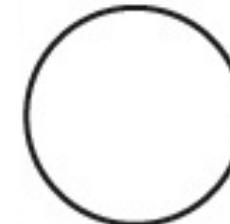


A typical stack

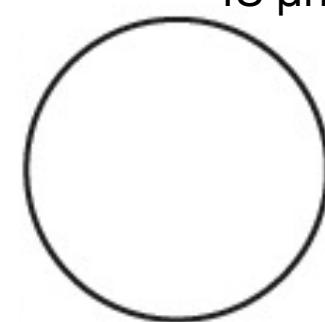
a



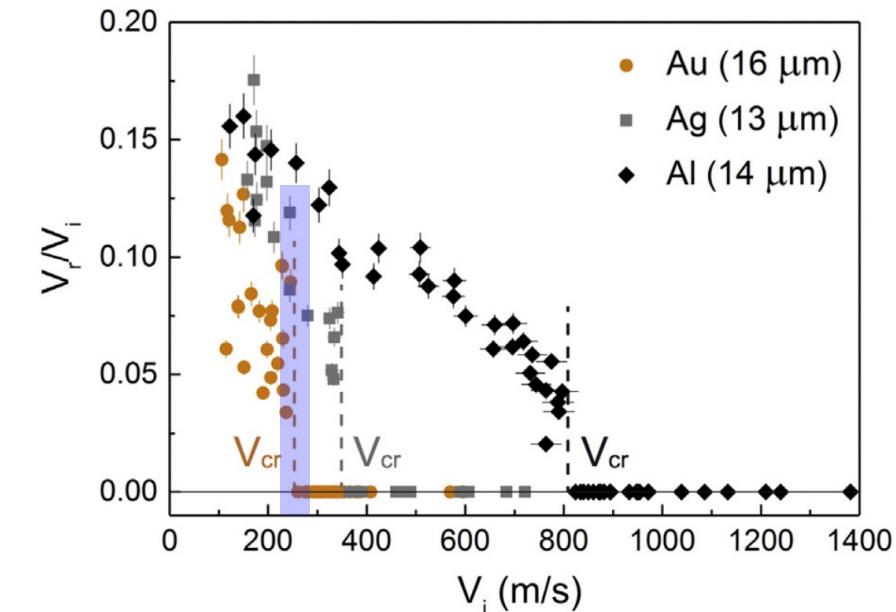
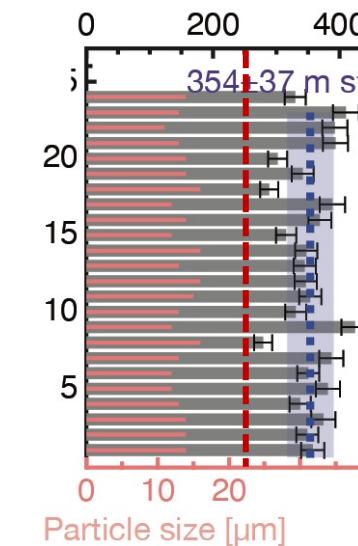
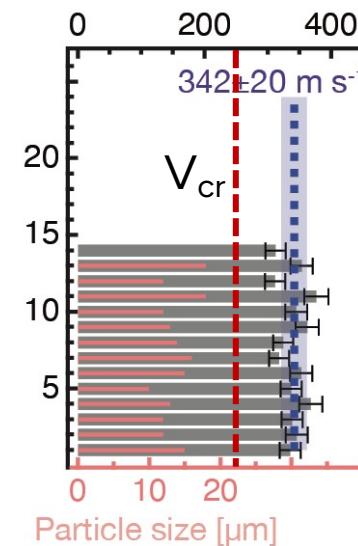
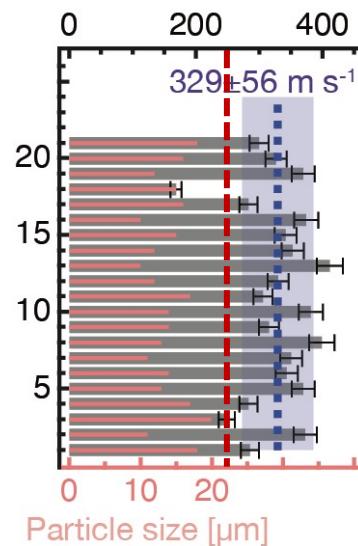
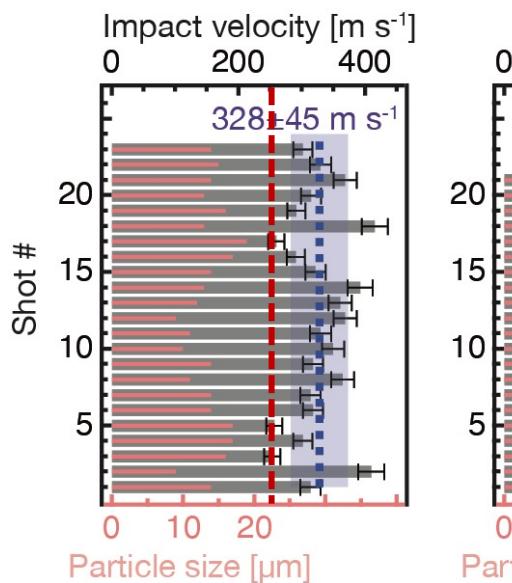
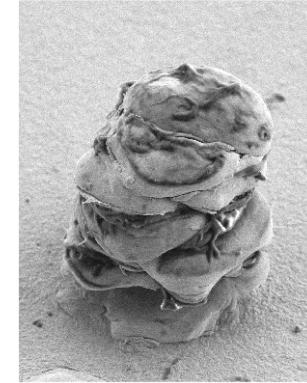
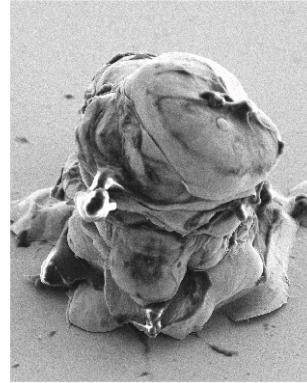
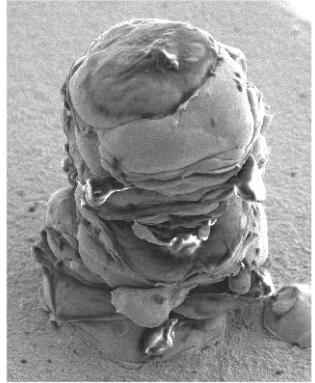
13 μm



18 μm

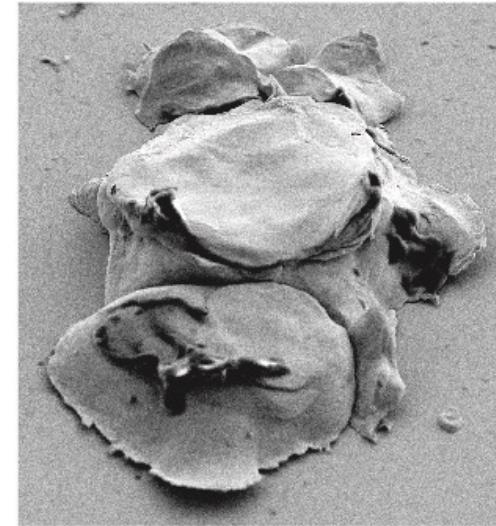
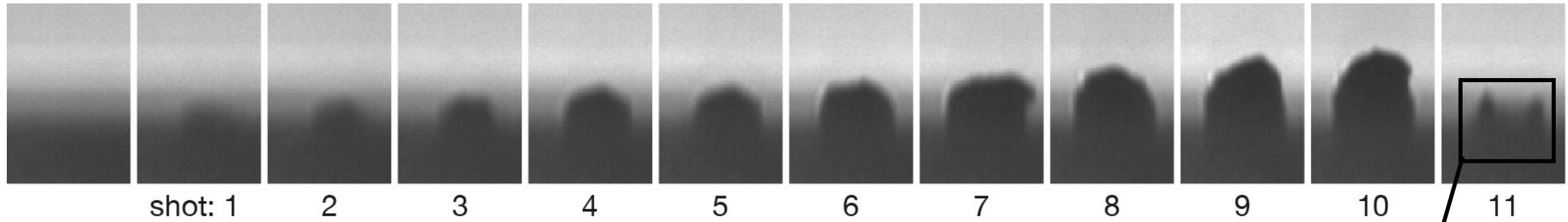


Successful coatings



Hassani-Gangaraj, M., Veysset, D., Nelson, K. A. & Schuh, C. A.. Appl. Surf. Sci. 476, 528–532 (2019).

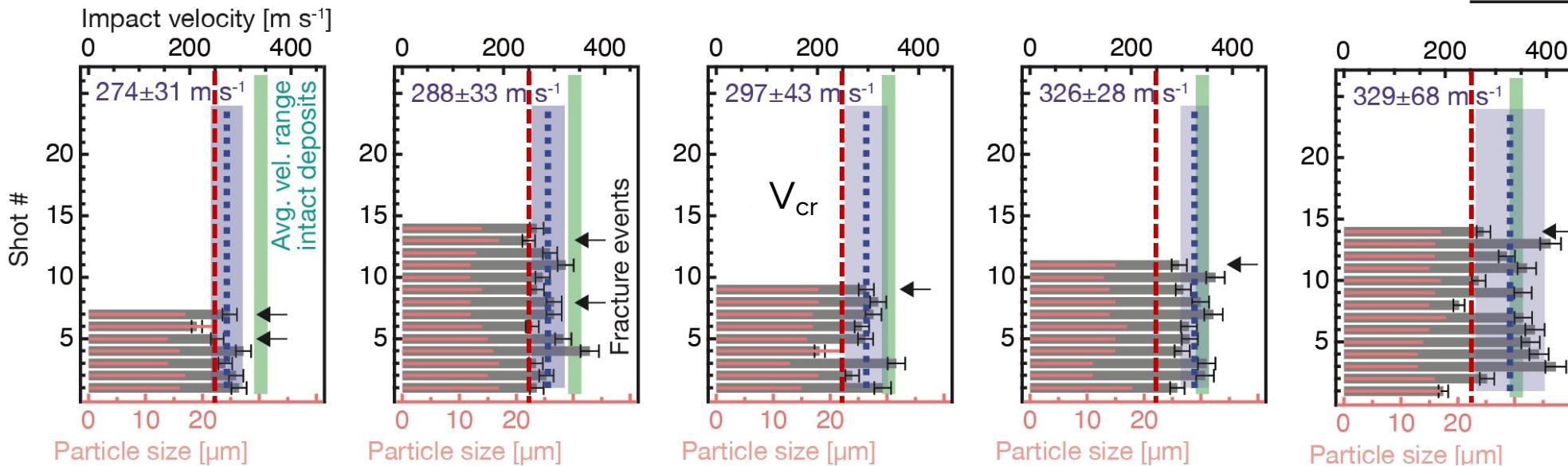
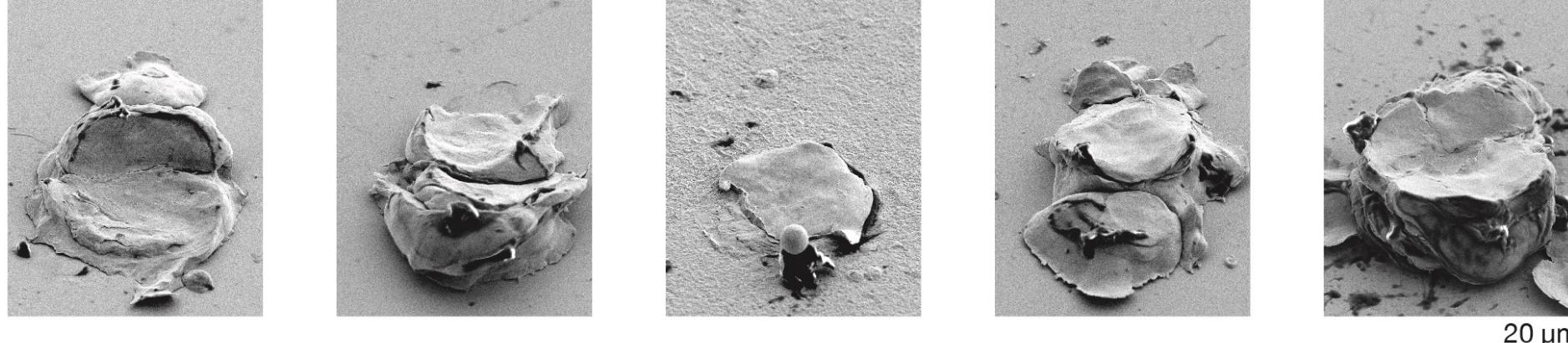
Eroded coatings



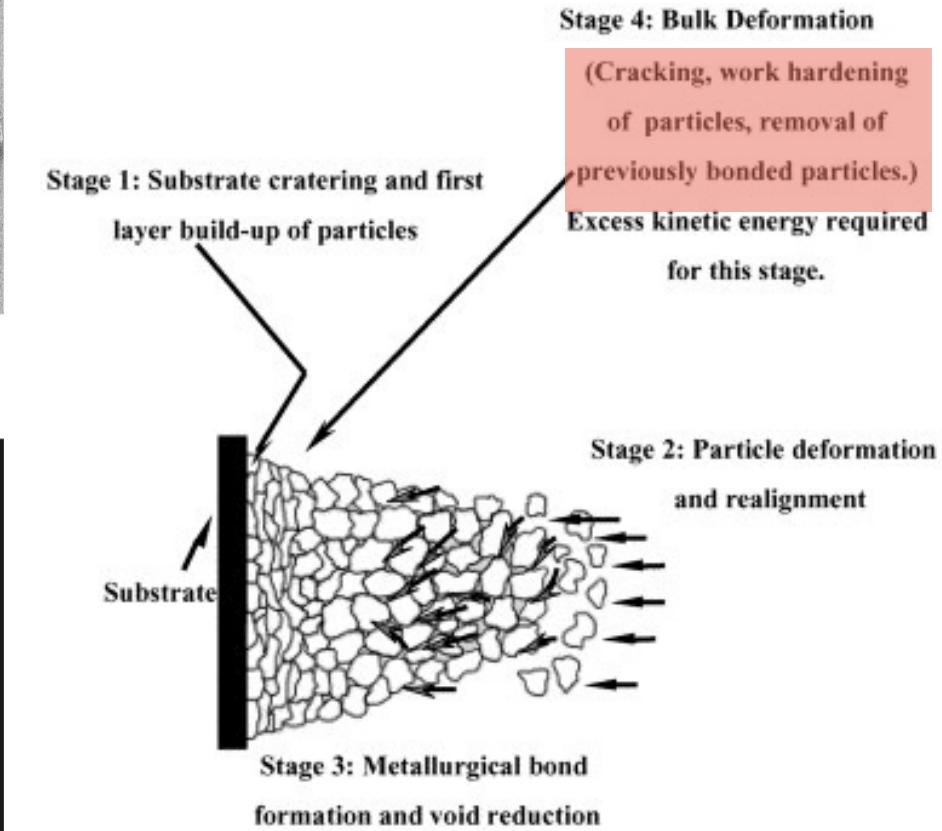
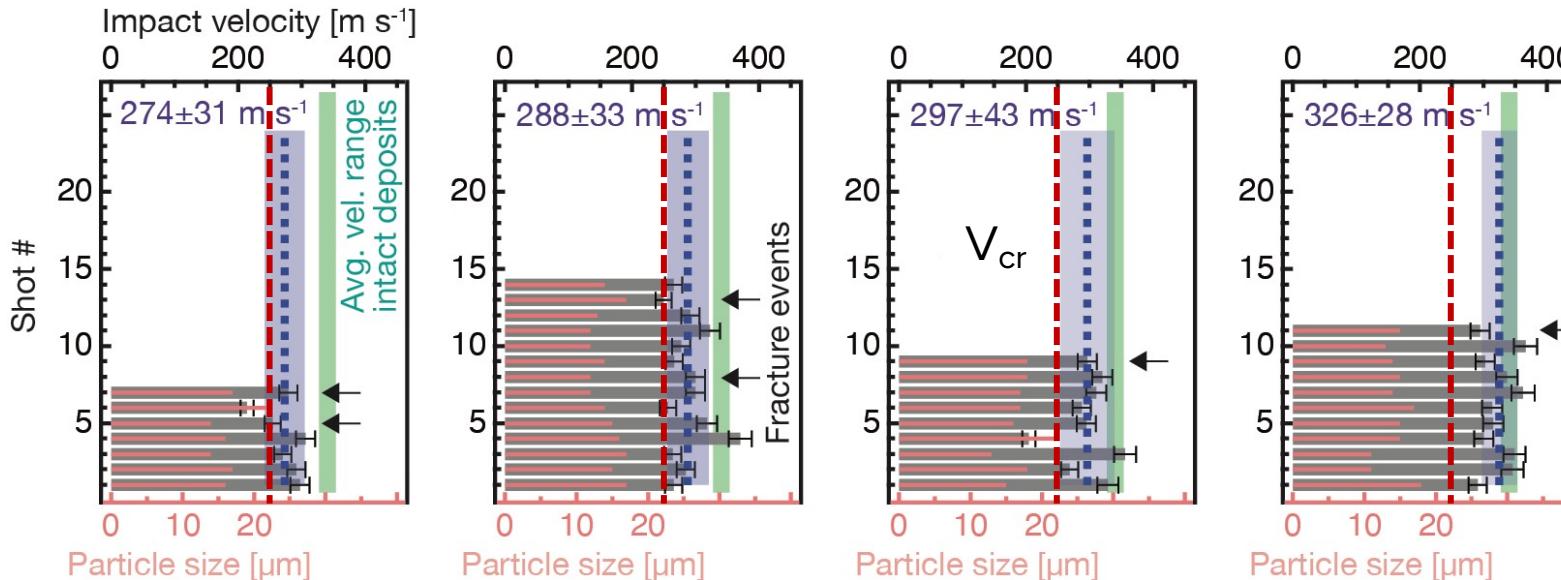
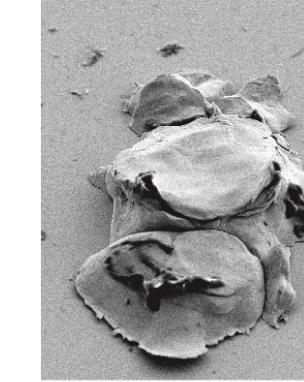
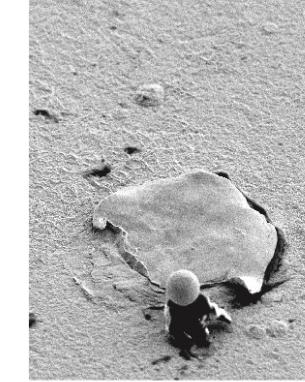
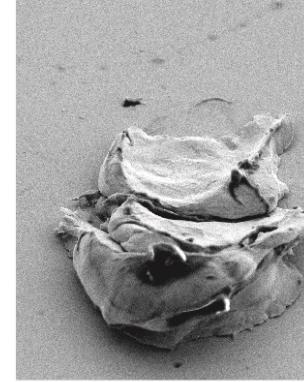
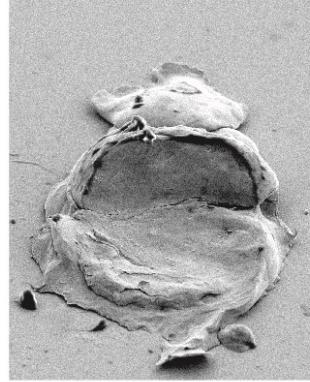
20 μm

16

Eroded coatings

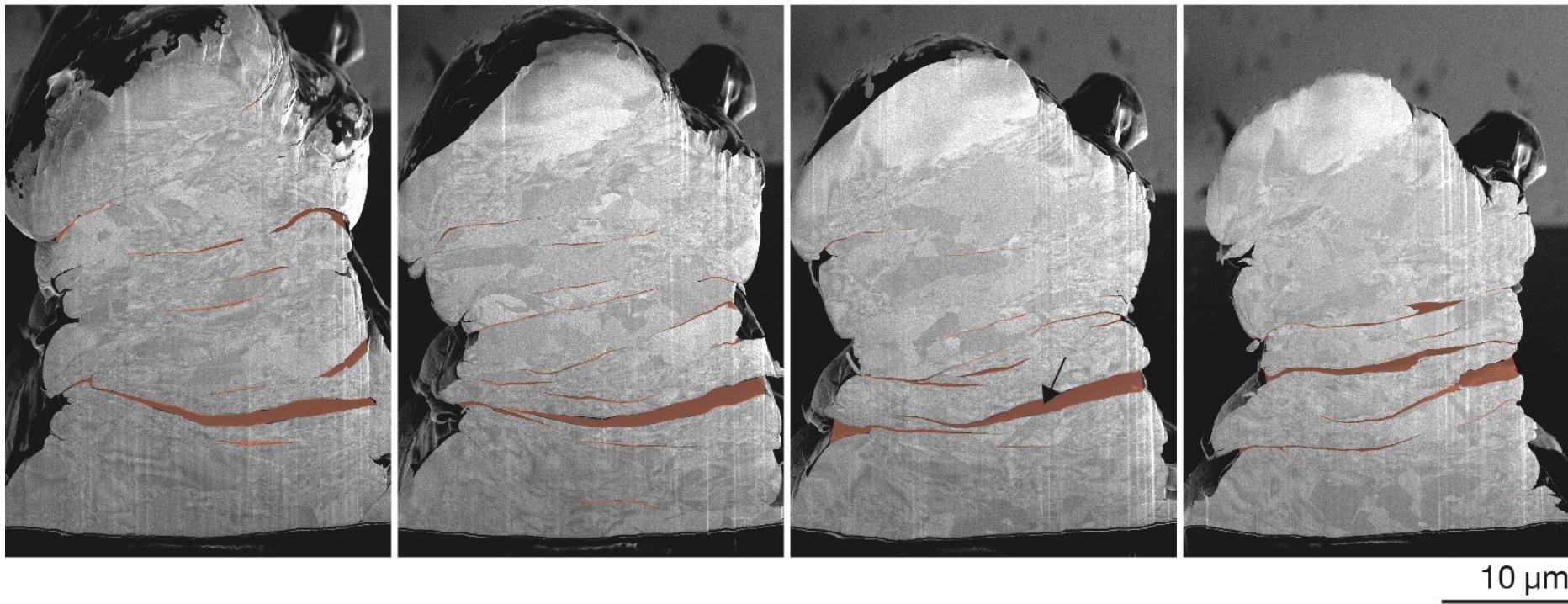


Erosion contributes to the coating efficiency at low v

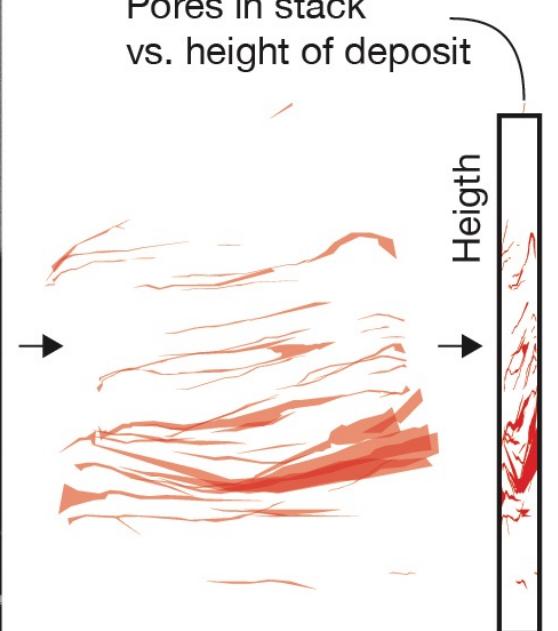


R.E. Teets, Surface and Coating Tech. (2002)

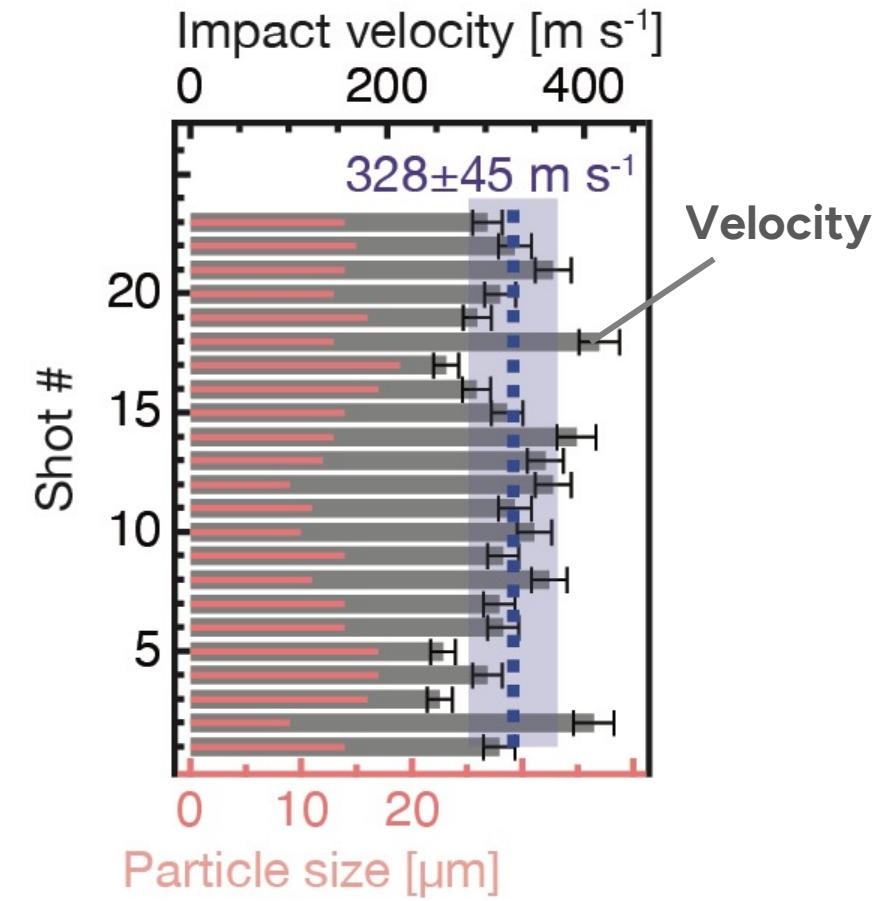
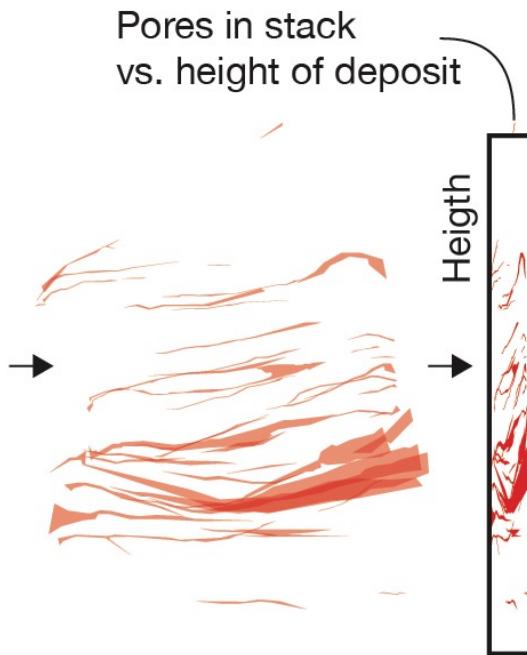
Particle-scale defects



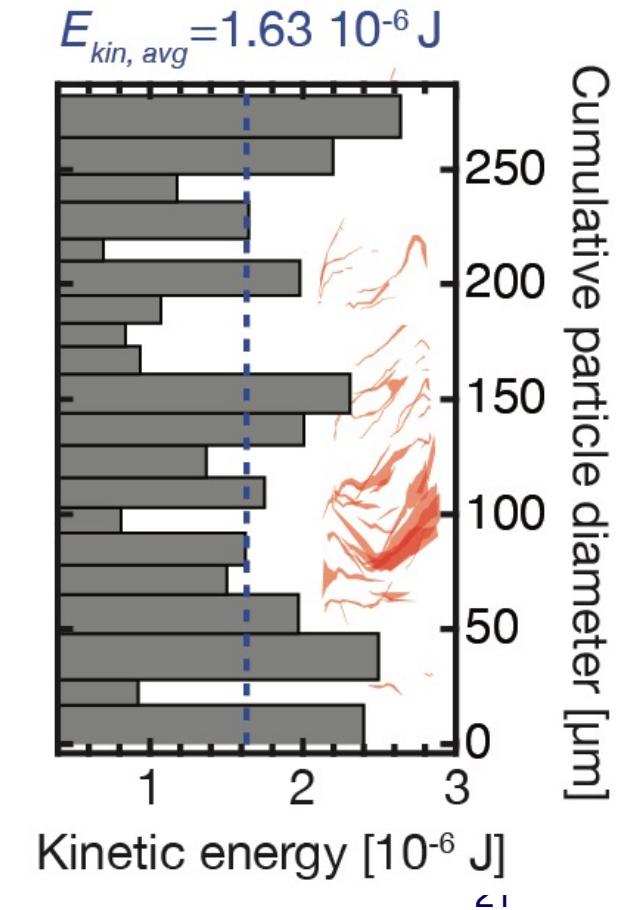
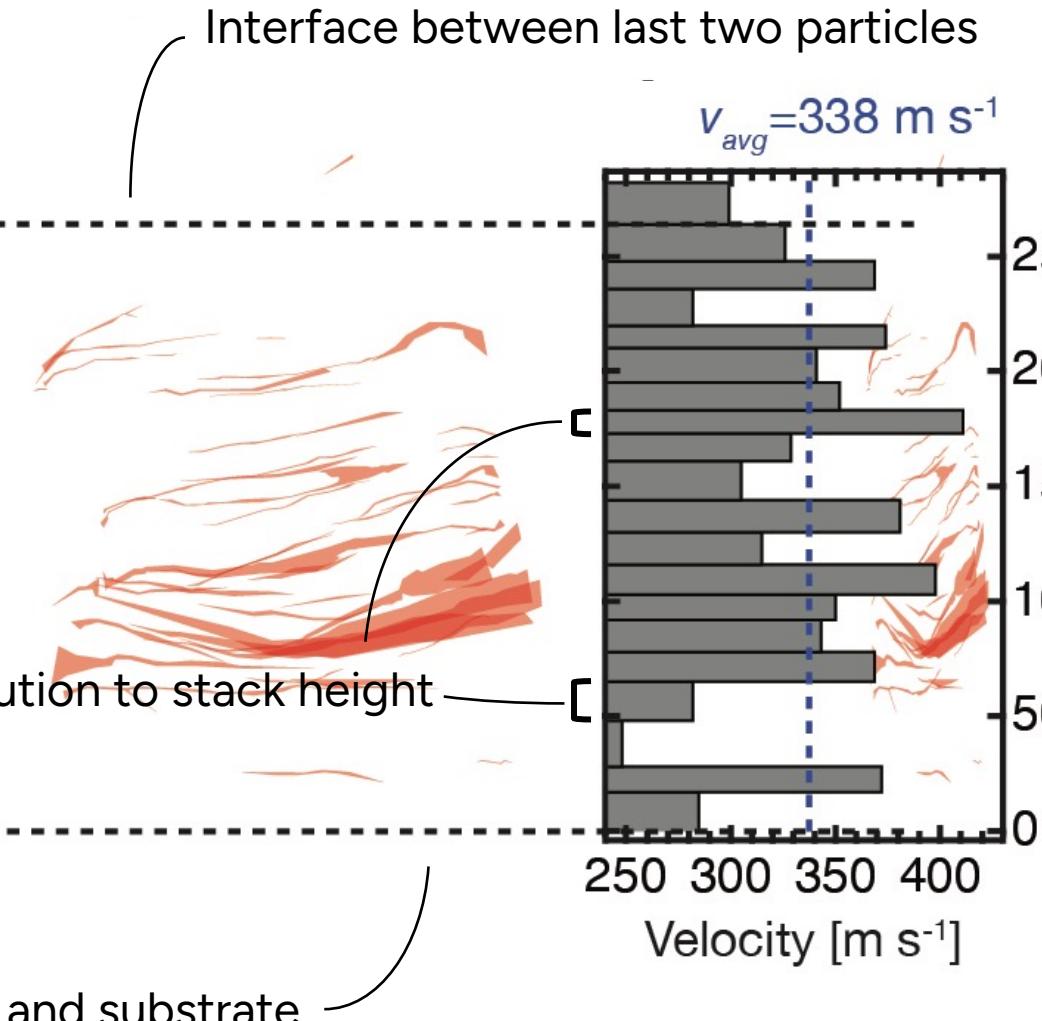
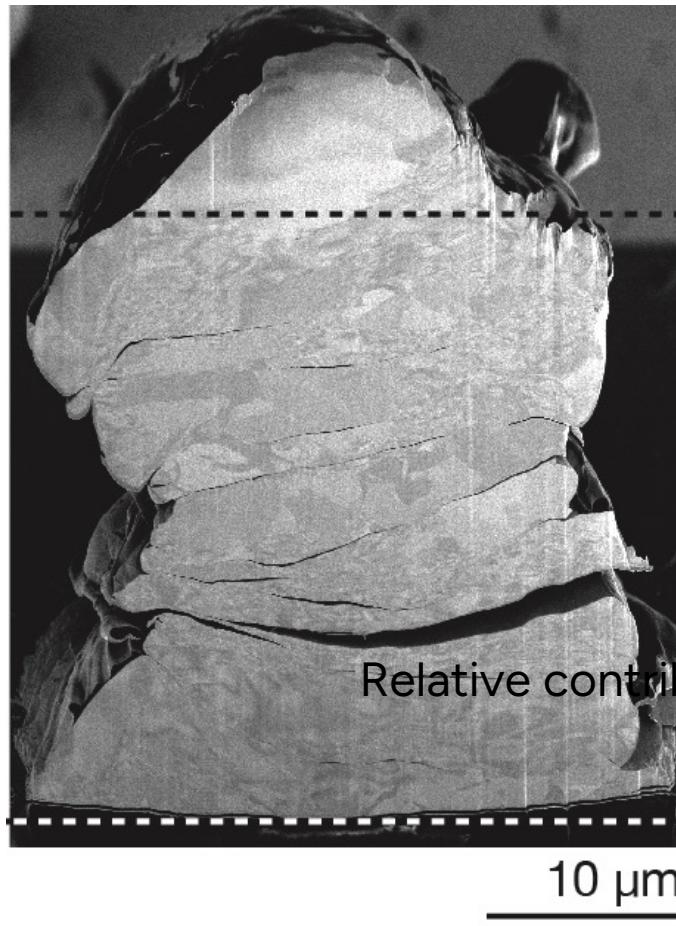
Pores in stack
vs. height of deposit



How to connect shot number with stack height?

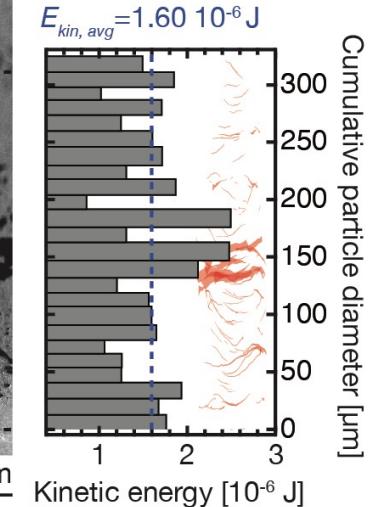
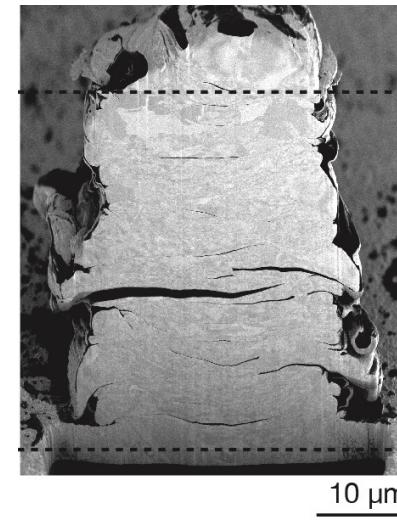
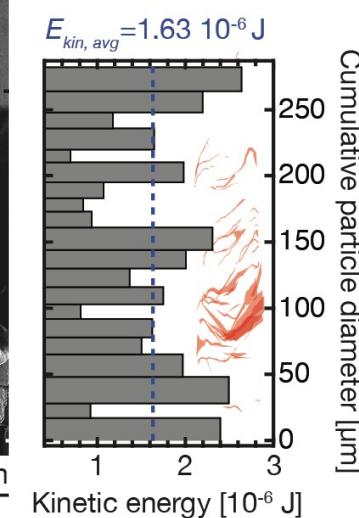
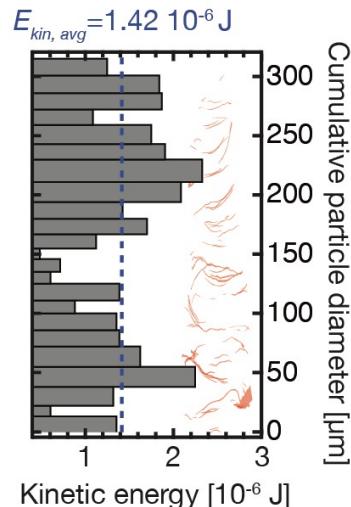
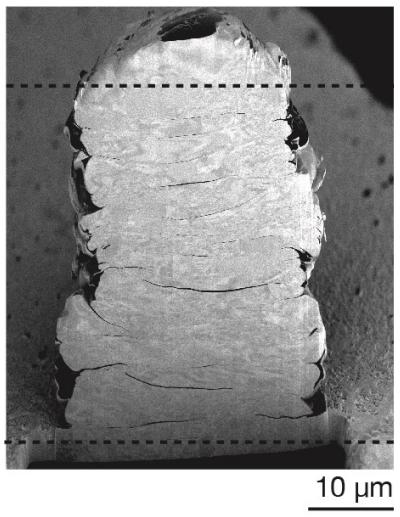


Align stack height with cummulative particle size

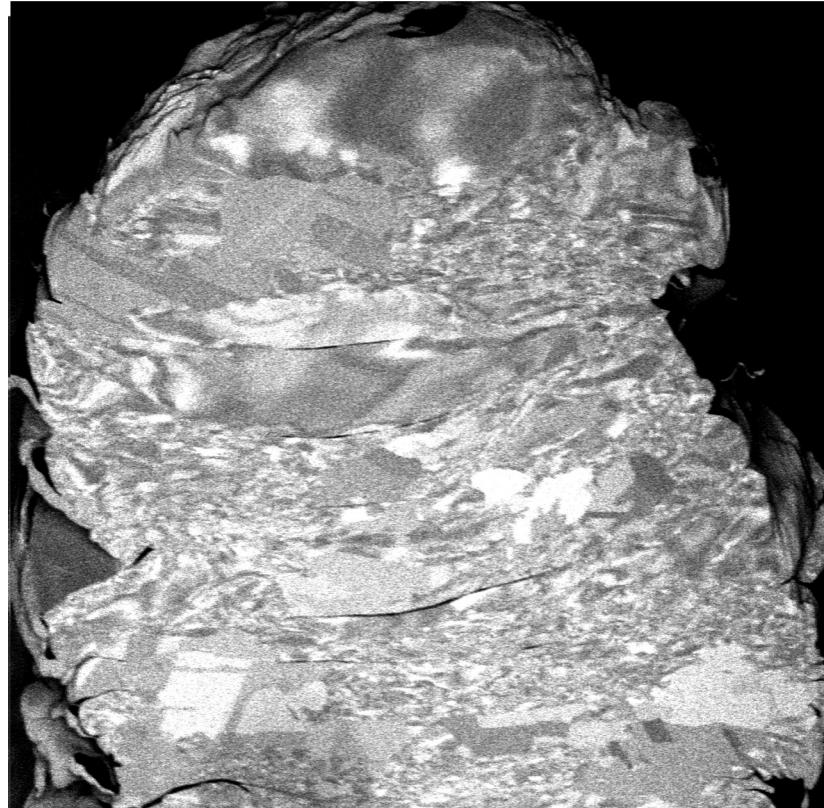


Interface between 1st particle and substrate

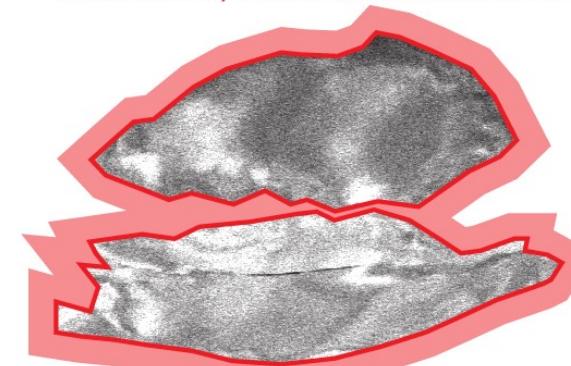
Low kinetic energy may contribute



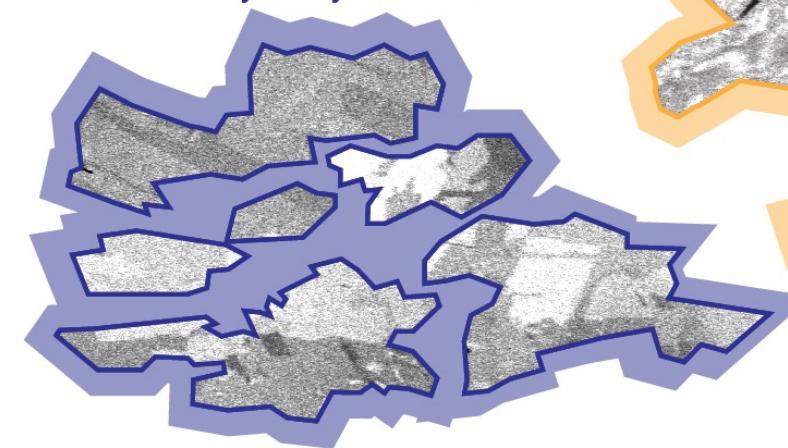
Microstructure evolution: ReX



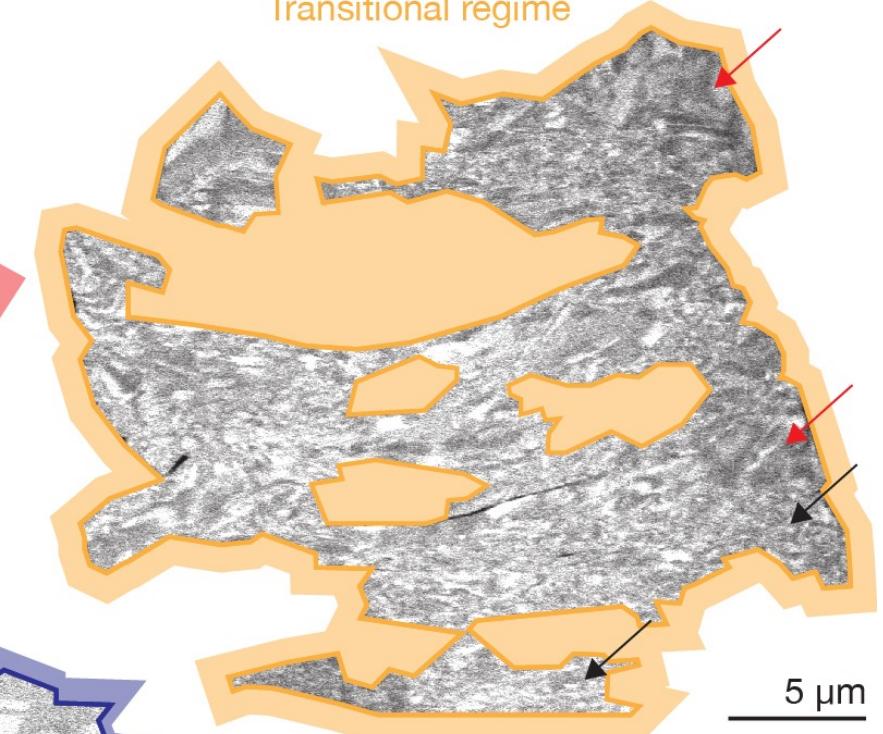
Deformed, initial microstructure



Fully recrystallized

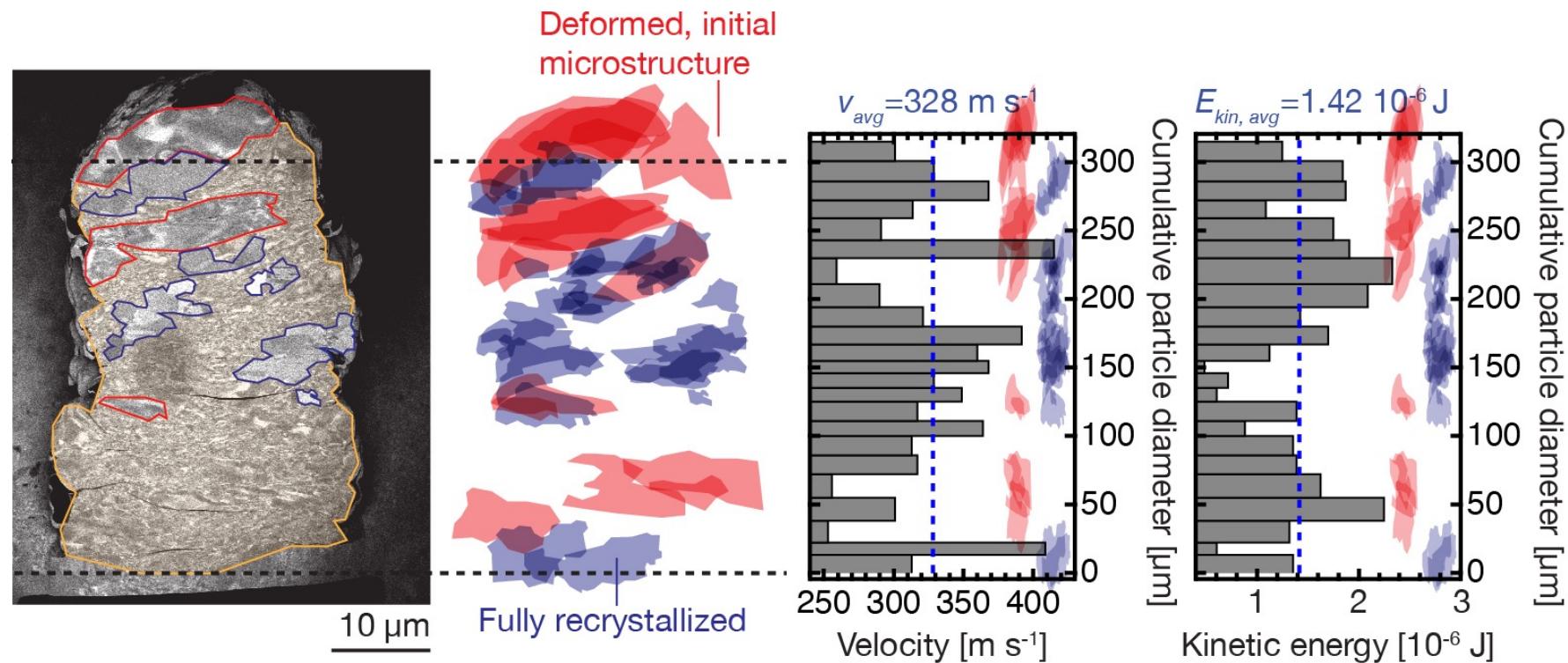


Transitional regime

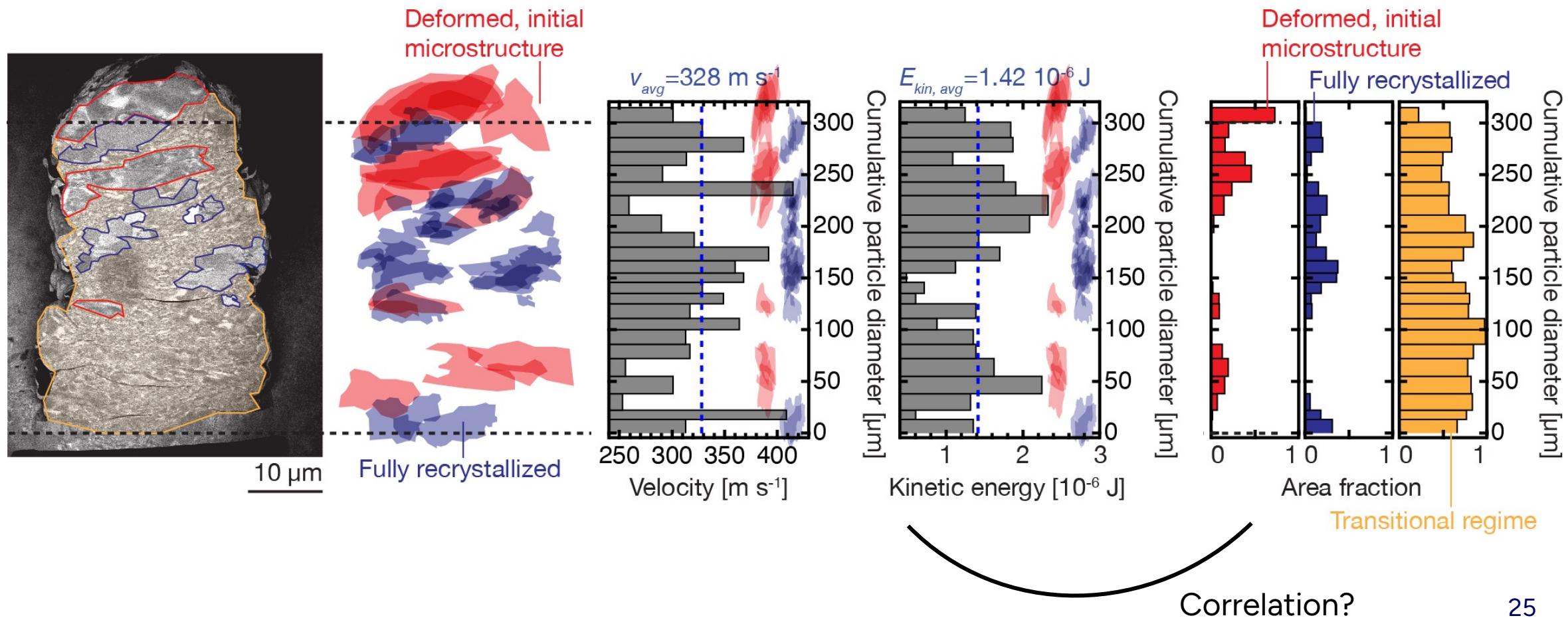


$5 \mu\text{m}$

Correlation of microstructure to kinetic parameters

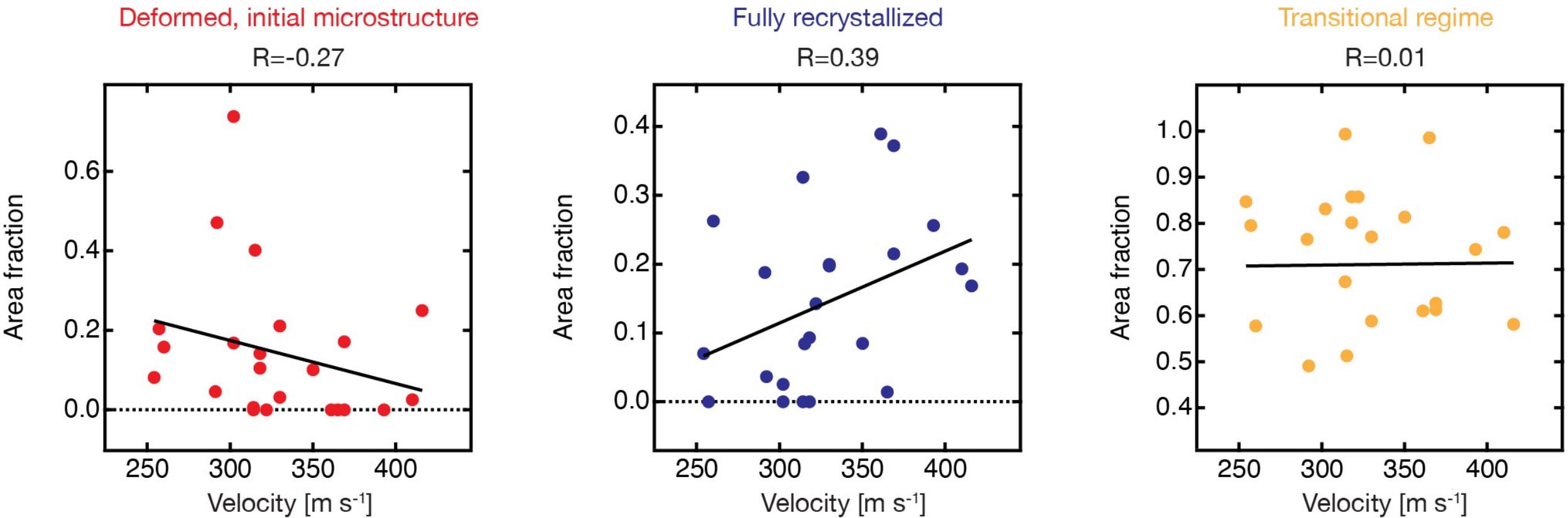


Correlation of microstructure to kinetic parameters



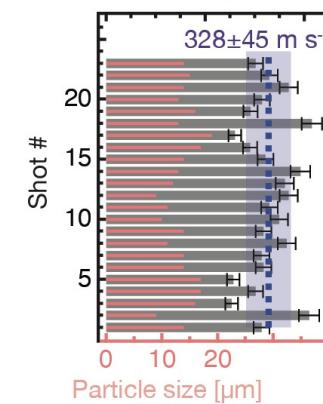
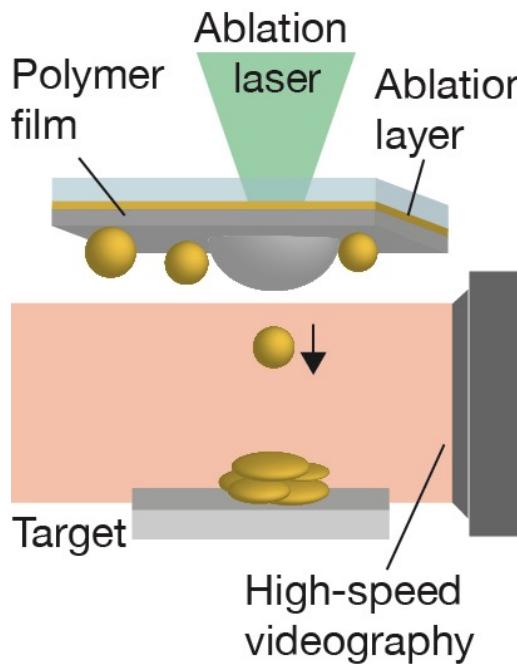
Correlation?

Correlation of microstructure to kinetic parameters

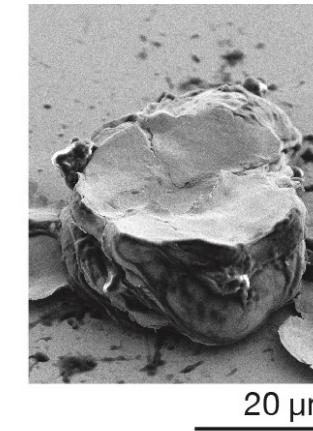


Many-particle testing as a future avenue for LIPIT

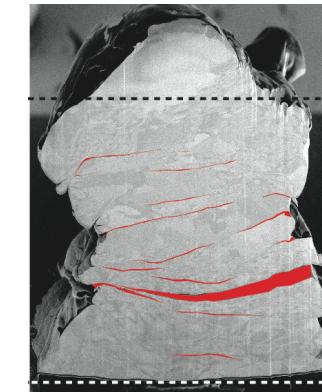
Experimental simulation of a cold-spray coating with single-particle impact data



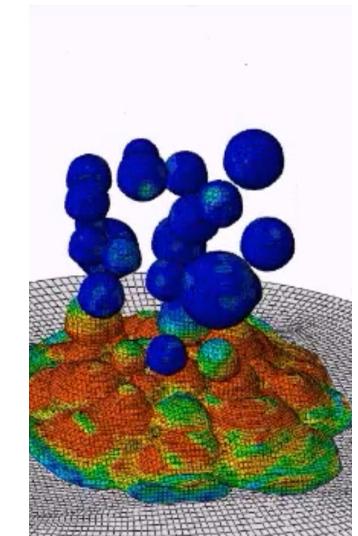
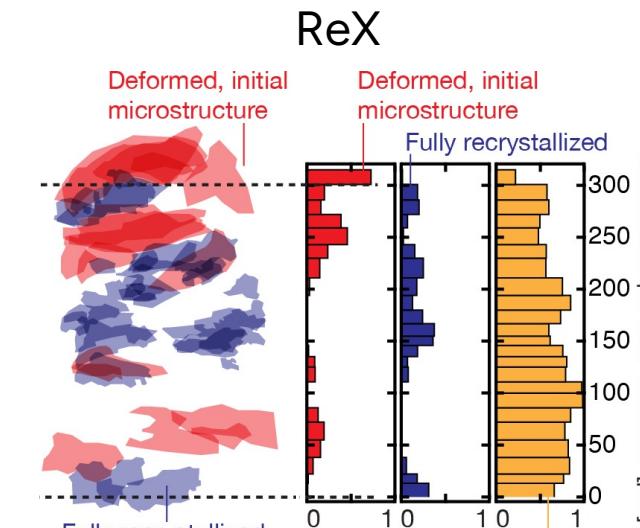
Erosion



Defects



Same scale as FEM



E. Liu et al., Surface and Coatings Tech. (2020)

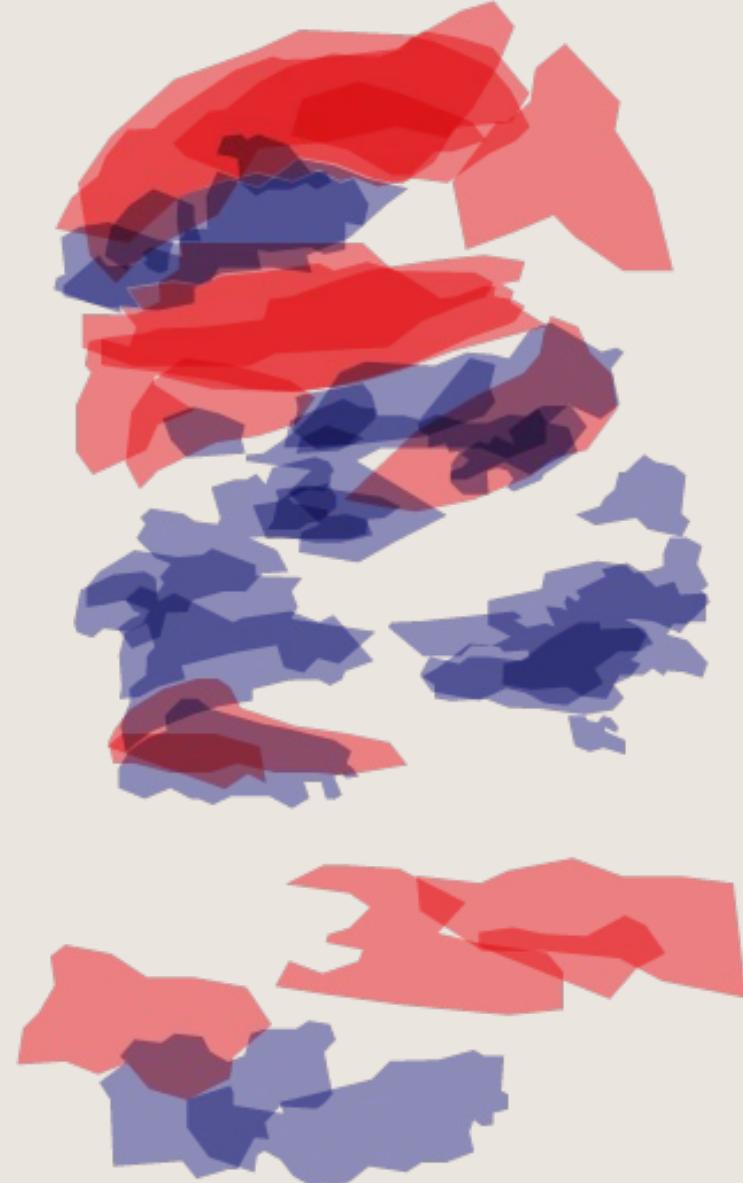


Thank you

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A. Reiser, C. Schuh., Towards an understanding of particle-scale flaws and microstructure evolution in cold-spray via accumulation of single particle impacts, arXiv.org, 2404.05601, 2024.