Building to last: challenges in additive manufacturing going from prototype to functional component

Angel Yanguas-Gil

Characterization of materials throughout their lifecycle through two different perspectives

- Advanced manufacturing perspective: beyond prototype and design
- Characterization perspective: knowledge and cultural gaps
- Suggestions

Perspective #1: Advanced manufacturing

Characterization of Materials Throughout Their Lifecycle

Challenge #1: application dependence

Example #1: additive manufacturing for nuclear chemical engineering

Liquid-liquid extraction equipment for advanced separations processes

- Custom annular centrifugal contactor (ACC) designs
  - ACC with enhanced mixing and residence time [1]
- Prototyping to functional 'end-use' equipment
- Complete multi-stage extraction systems
  - Multi-stage 2-cm ACC assembly for HCl-based process chemistry [2]
- Scaled-down designs for waste minimization
  - 1.25cm rotor contactor (enhanced residence time design)[3]

For more information contact Kent Wardle (kwardle@anl.gov)

Example #2: additive manufacturing for biochemical synthesis

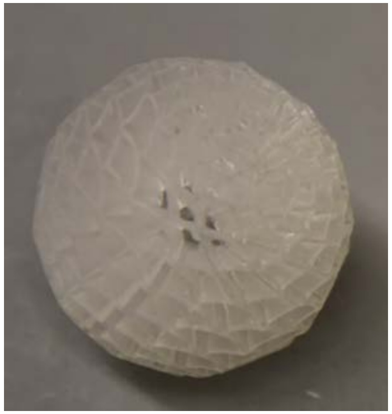
Integrated functional structures providing

1) high mass transfer between gas-liquid-solid interfaces
2) Desired metabolic activities in bioprocessing

Goals:

- Achieve higher survival rates of microbes through controlled bioaffinity
- Higher process efficiency

Example: syngas fermentation



3D printed biocarrier

For more information contact Meltem Urgun Dermirtas (demirtasu@anl.gov)

Challenge #1: application dependence

Performance metrics and degradation mechanisms of the materials are strongly application-dependent

For many of these applications we don’t even know what the lifecycle of the material would be.

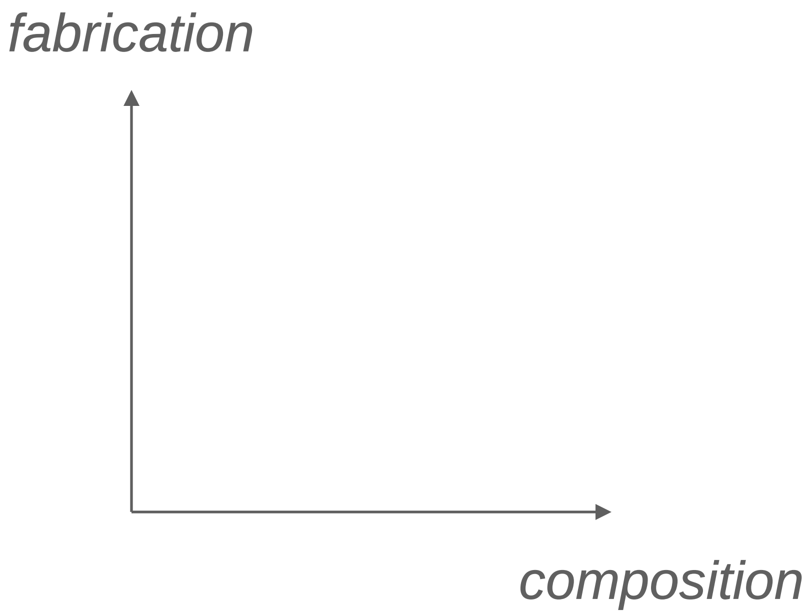
Unknown material reliability can have a big impact in the techno-economic assessment of a technology: down time

Characterization over the life cycle of a material should be built into the projects

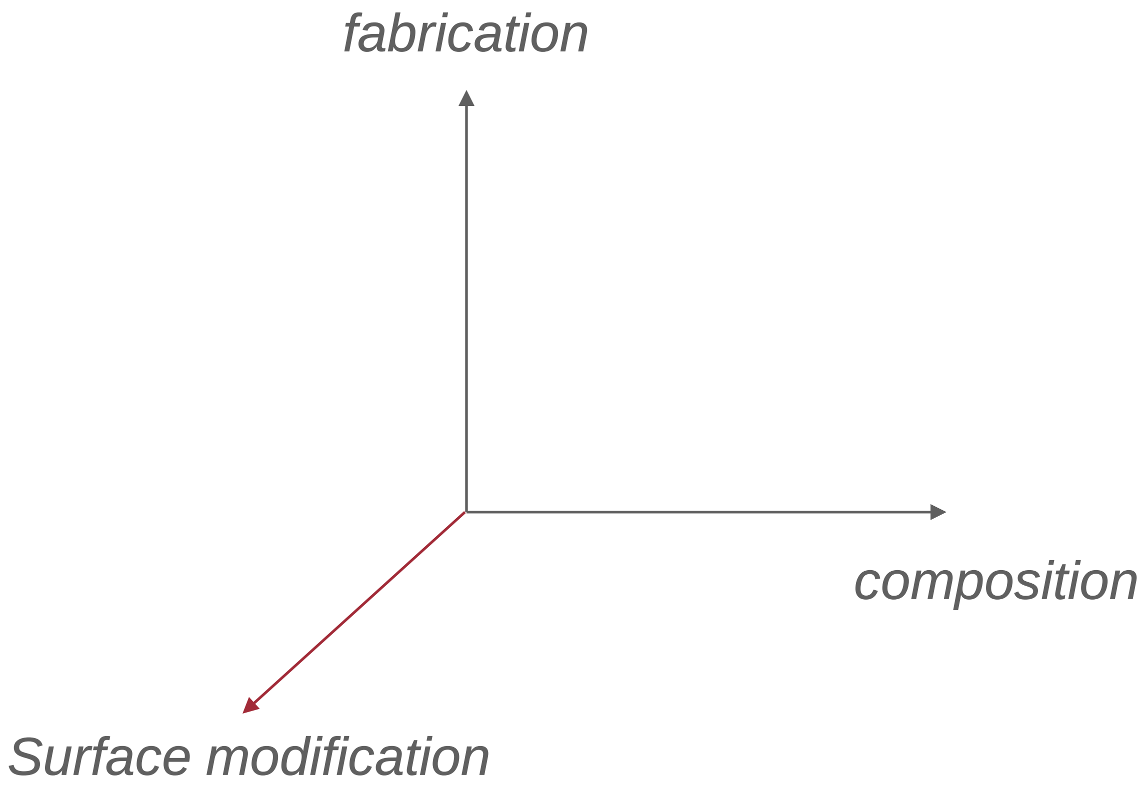
Characterization of Materials Throughout Their Lifecycle

Challenge #2: materials diversity

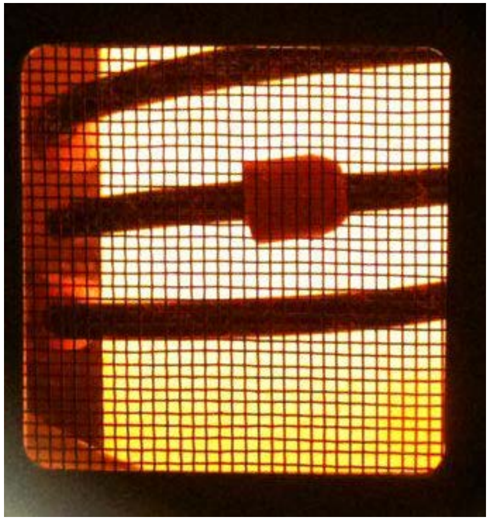
Materials diversity



Materials diversity



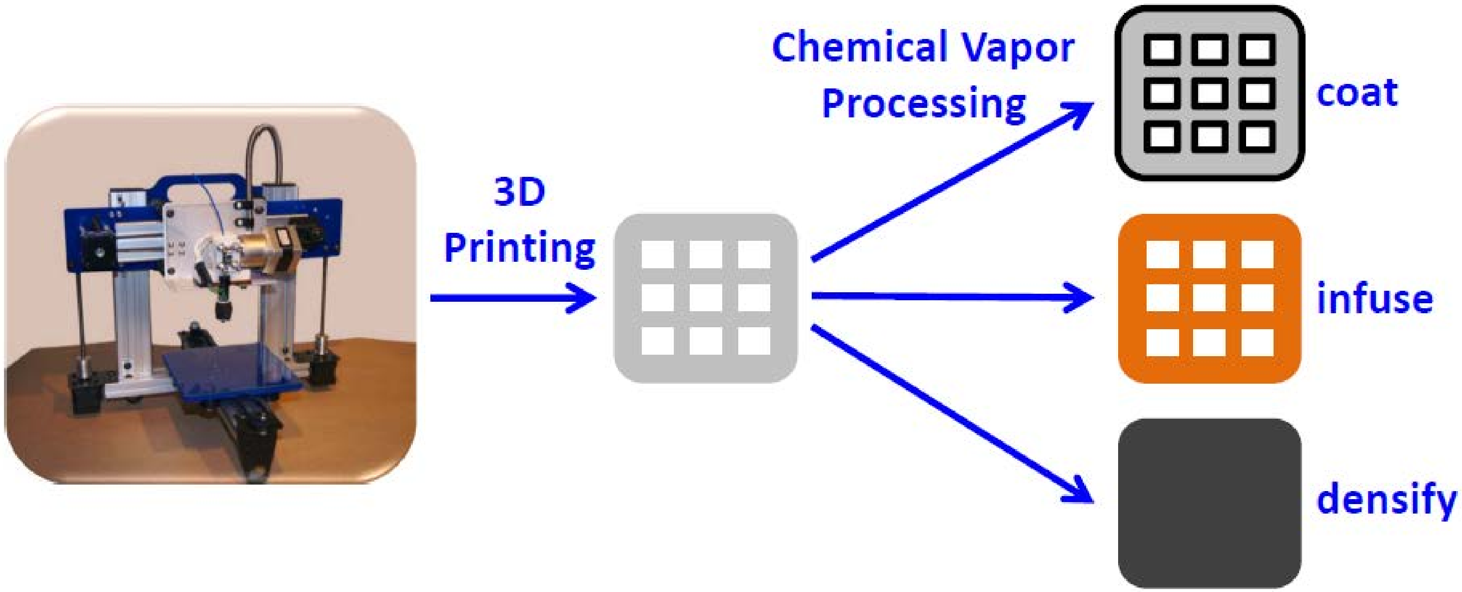
Example #1: Plasma processing



Plasma-based modification of polymers is a well-established field

Surface and subsurface modification, functionalization, and grafting

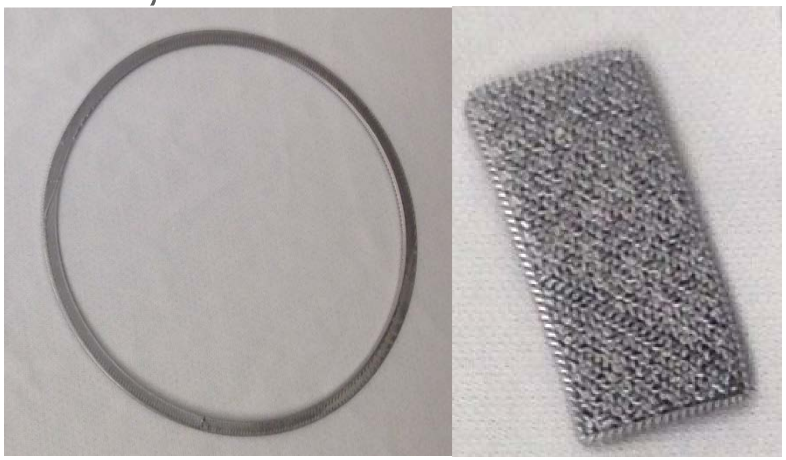
Example #2: Chemical Vapor Processing for Additive Manufacturing



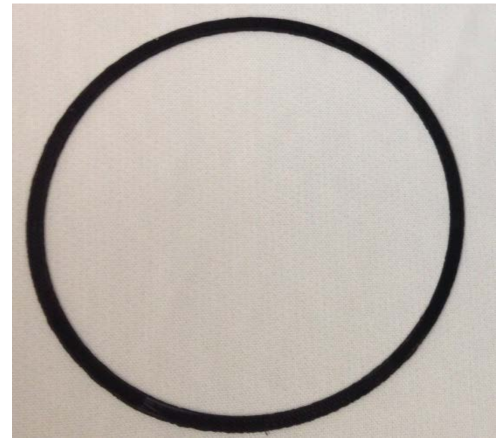
For more information contact Jeffrey W. Elam (jelam@anl.gov)

CVPAM on ABS 3D Printed Parts

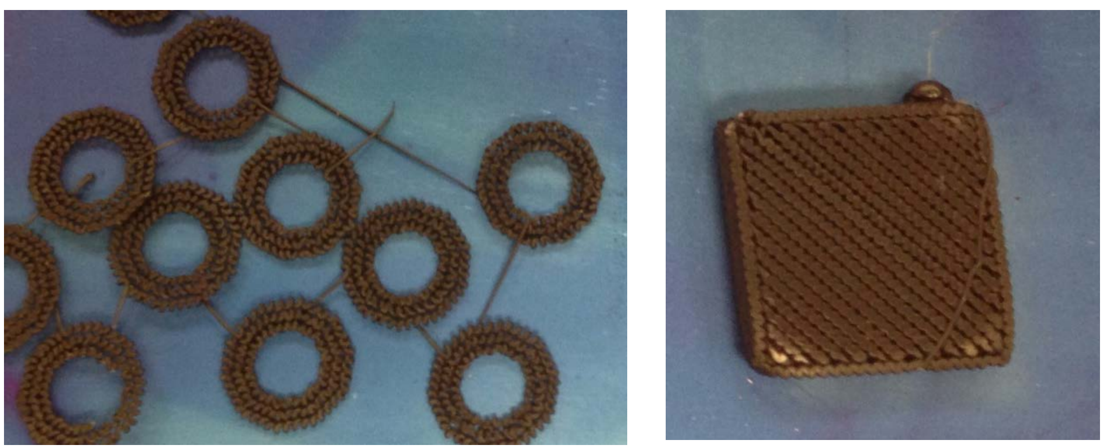
W, 85 ^oC



ZnO, 85 ^oC



Al_2O_3, 85 ^oC

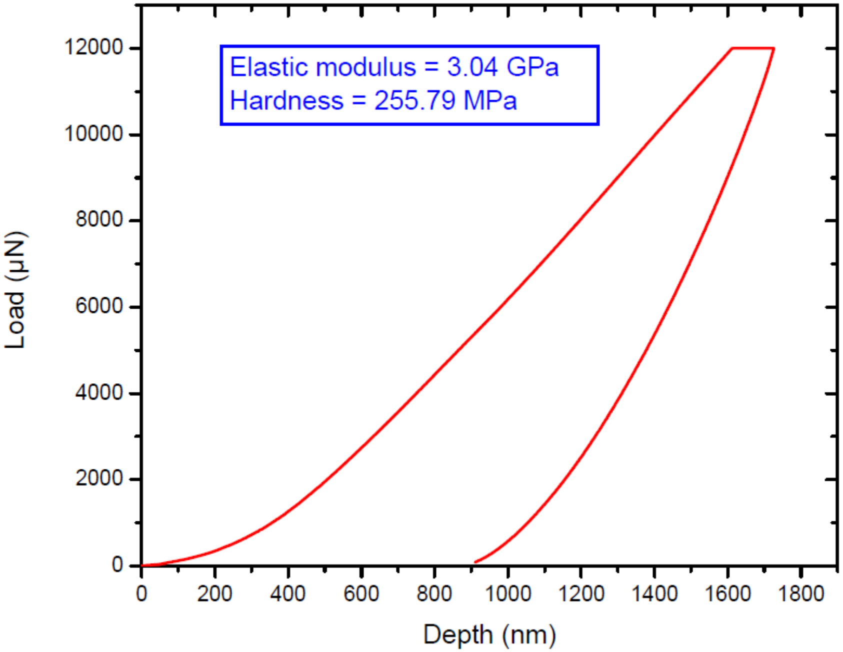


- Dielectrics:
  - Al2O3, MgO
- Semiconductors:
  - ZnO, TiO2
- Metals:
  - W
- Composites:
  - W-AlF3, W-Al2O3

CVPAM for Wear Resistance and Lubrication

3D-Printed Bushings
- Al_2O_3 for wear-resistance
- MoS_2 for lubrication

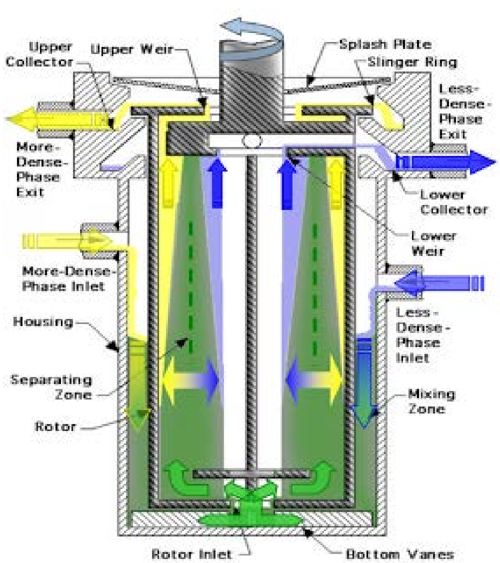
Tribology Laboratory (ES)
- Ali Erdemir, Giovanni Ramirez
- Nanoindentation (load-displacement)
- Pin on disc (friction, wear)



Tungsten-Aluminum Fluoride Coatings for Chemical Robustness

Annular Centrifugal Contactor (Kent Wardle, NE)

- Compact mixer/centrifuge for nuclear fuel
- 3D printed parts, ABS polymer
- Problem: embrittlement in mineral acids and solvents



ALD W-AlF_3

- ALD composite material Developed for Li battery cathode protection
- Insoluble in HF acid
- Insoluble in organic solvents

3D printed components of annular centrifugal contactors coated with 10 nm ALD $WAlF_x$ coatings.

Challenge #2: Materials diversity

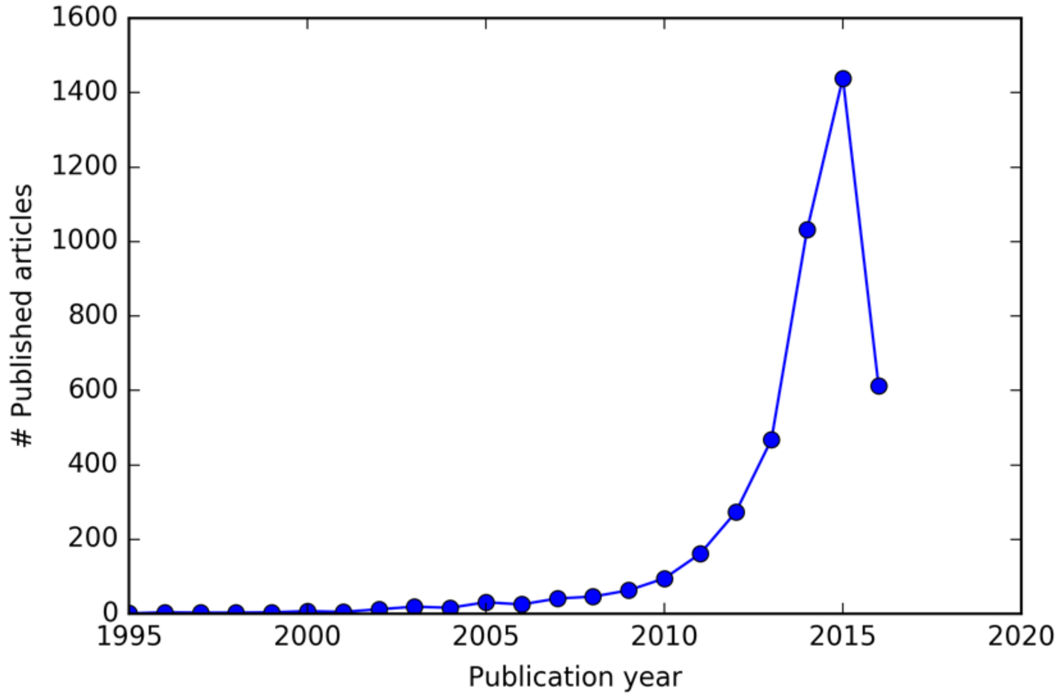
When the surface functionality becomes relevant, we are adding an extra degree of complexity

Information available on the impact of fabrication on the reliability of 3D printed materials is insufficient

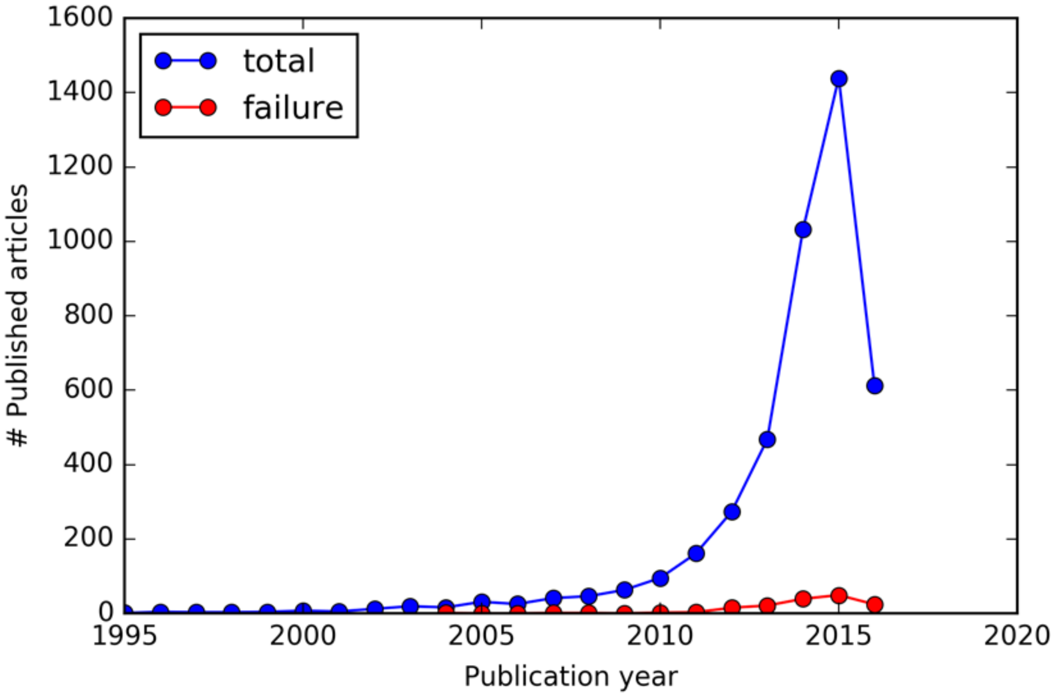
Characterization of Materials Throughout Their Lifecycle

If you are trying to develop functional additive manufacturing materials, where do you look for information on long-term behavior?

Looking at AM scientific literature



Looking at AM scientific literature



Only 3% of the sampled papers emphasize reliability or failure

Only 5% of the sampled papers emphasize reliability or failure or degradation

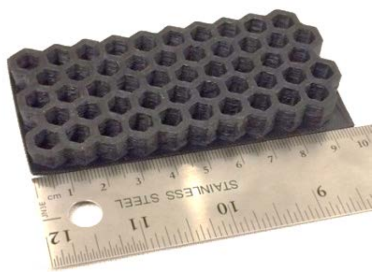
Many of these papers target metal AM

The state of the art is clearly insufficient to help us understand the reliability of our materials and our parts, and consequently of our processes

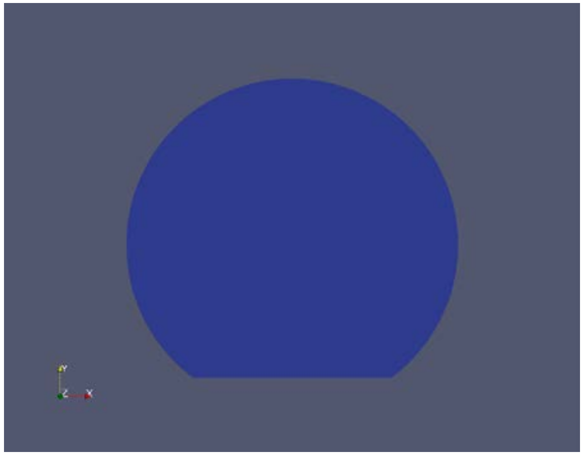
Perspective #2: Characterization point of view

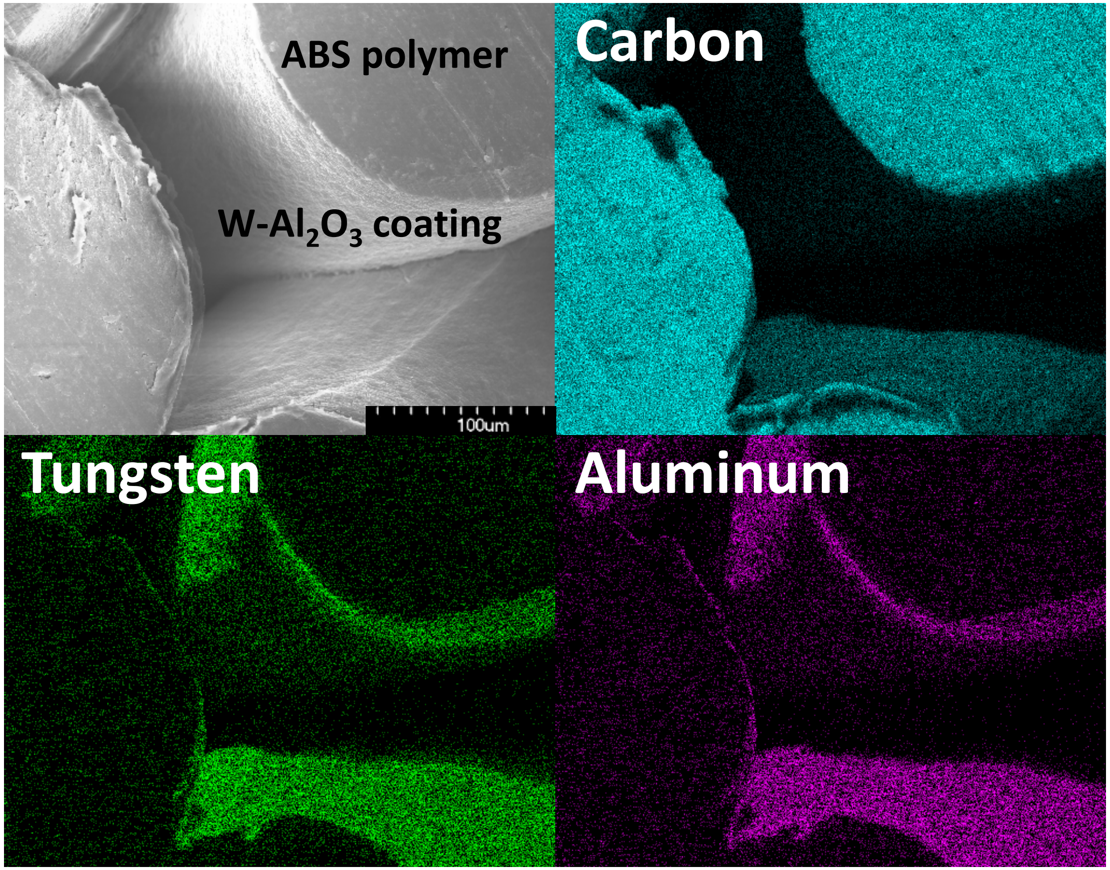
We can combine experimental and simulation techniques to characterize properties and degradation

Electron multiplier structures



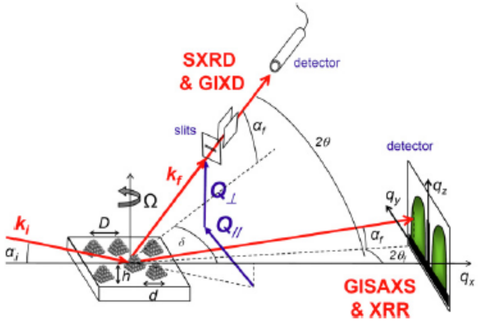
Polymer infiltration

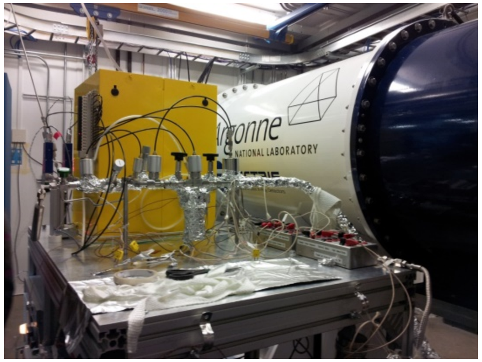


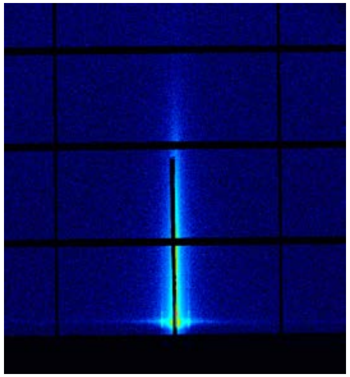


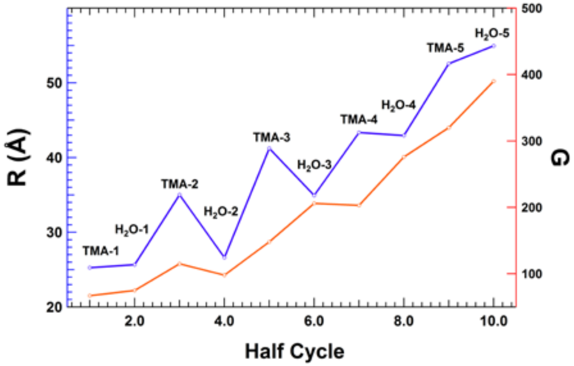
We can even design in-situ experiments

In-situ GISAXS of chemical vapor processing in Block Copolymer Lamellae









But…

But…

The challenge is that process development and detailed characterization are not highly compatible:

- Timescale
- Funding
- Different skillsets and communities

Conclusions and suggestions

Increased focus on reliability and performance

Consolidate existing published research

Improved metadata to ease data exchange and evaluation

Parts for info program to incentivize characterization of 3D printed materials

Thanks!