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Manufacturability considerations for copper/copper alloy aerospace parts using metal powder material extrusion

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Introduction

- Powder-based metal additive manufacturing technologies have made a very large impact on the design of aerospace-grade parts in recent years.
- Most of this has been based on Powder Bed Fusion (PBF) – SLM/DMLS, EBM, SLS
  - Design freedom
  - Lightweighting
  - On-demand spare parts
  - Re-manufacturing

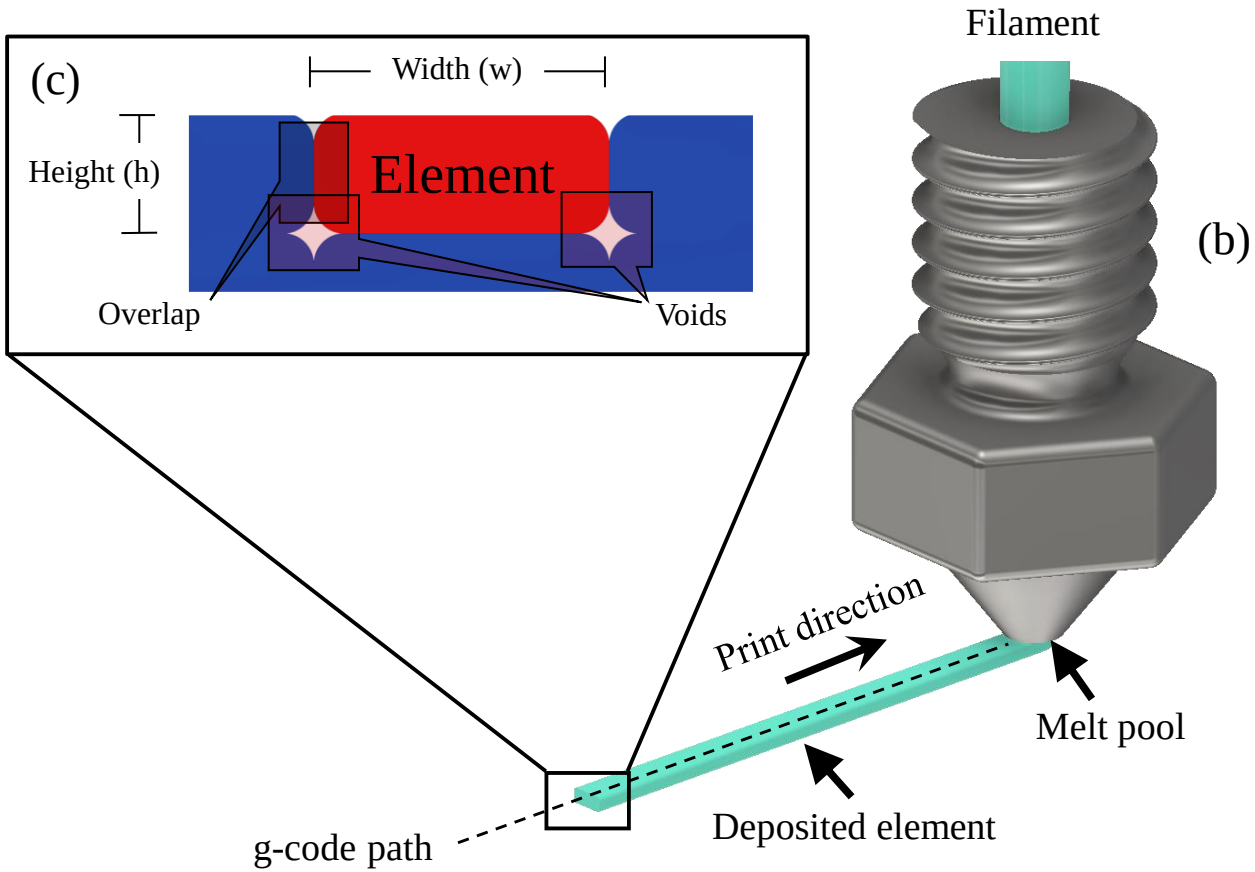
https://www.sciencedirect.com/science/article/pii/S2238785422011607

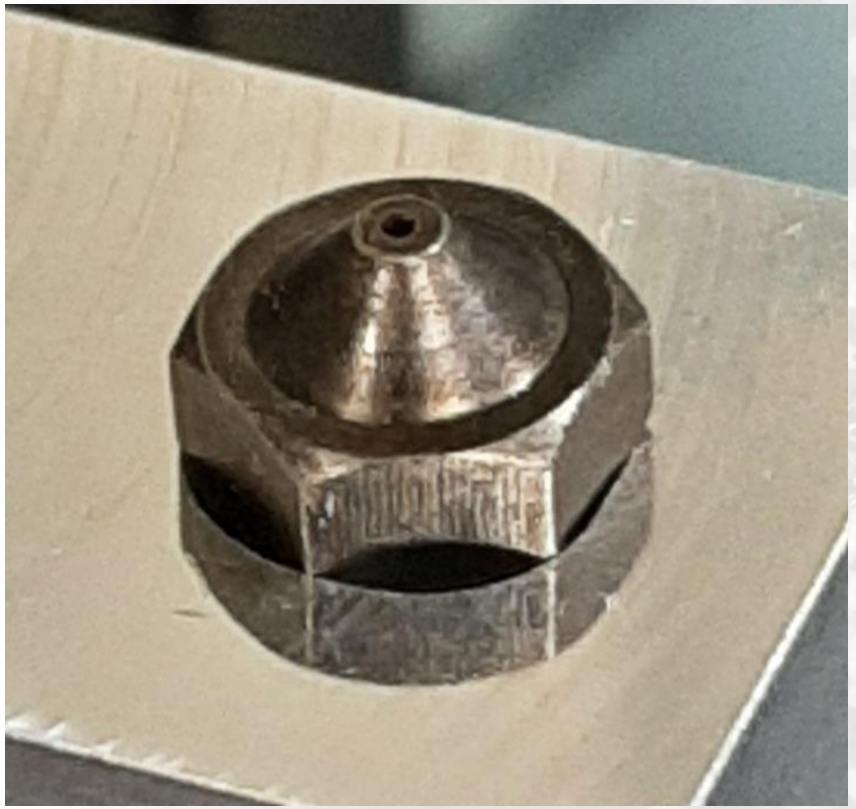
https://link.springer.com/article/10.1007/s11665-022-06850-0

Introduction

- However, there are still major challenges
  - Issues processing soft non-ferrous metals (copper, aluminum, precious metals)
  - Processing cost
  - Residual stresses
  - Equipment cost and complexity
  - Very high scrap rate
- A hybrid of classic powder injection molding and additive manufacturing could be a promising future answer
  - Powder material extrusion – based on FFF process but using feedstock with 60-90% powder with a thermoplastic binder
  - Metal, ceramic, and cermet powder can be used
  - Significant energy use reduction, even with debinding and sintering

Powder Material Extrusion

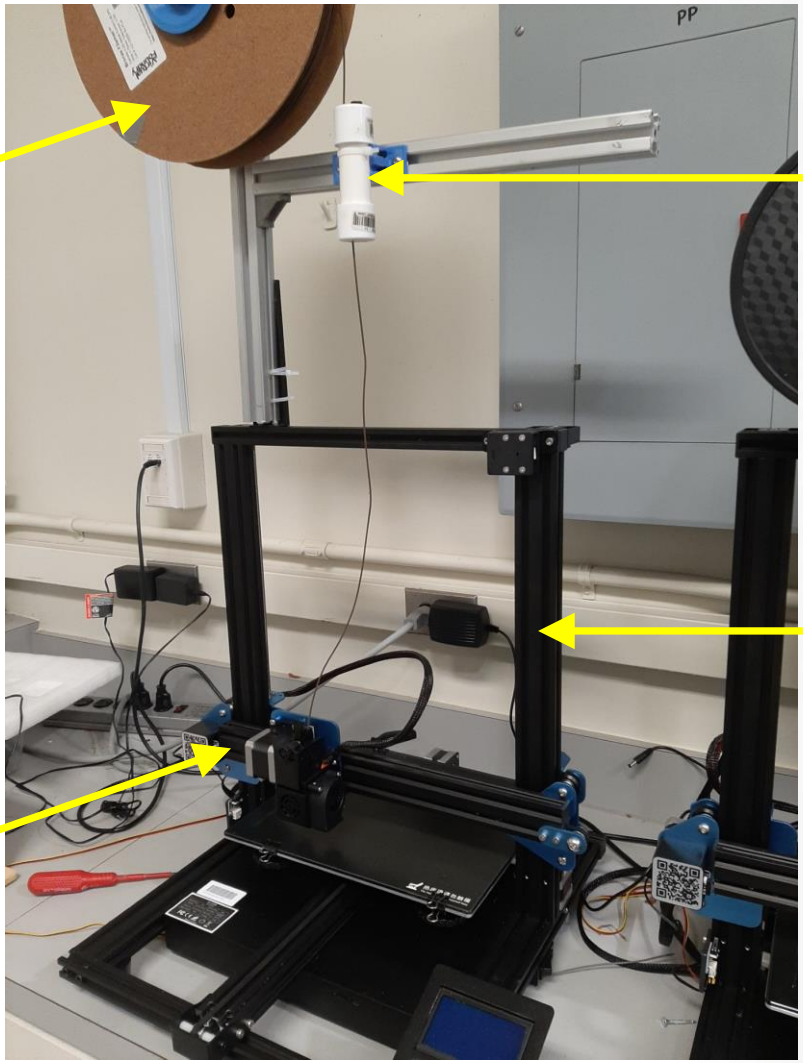




Powder Material Extrusion

Feedstock – 90% powder

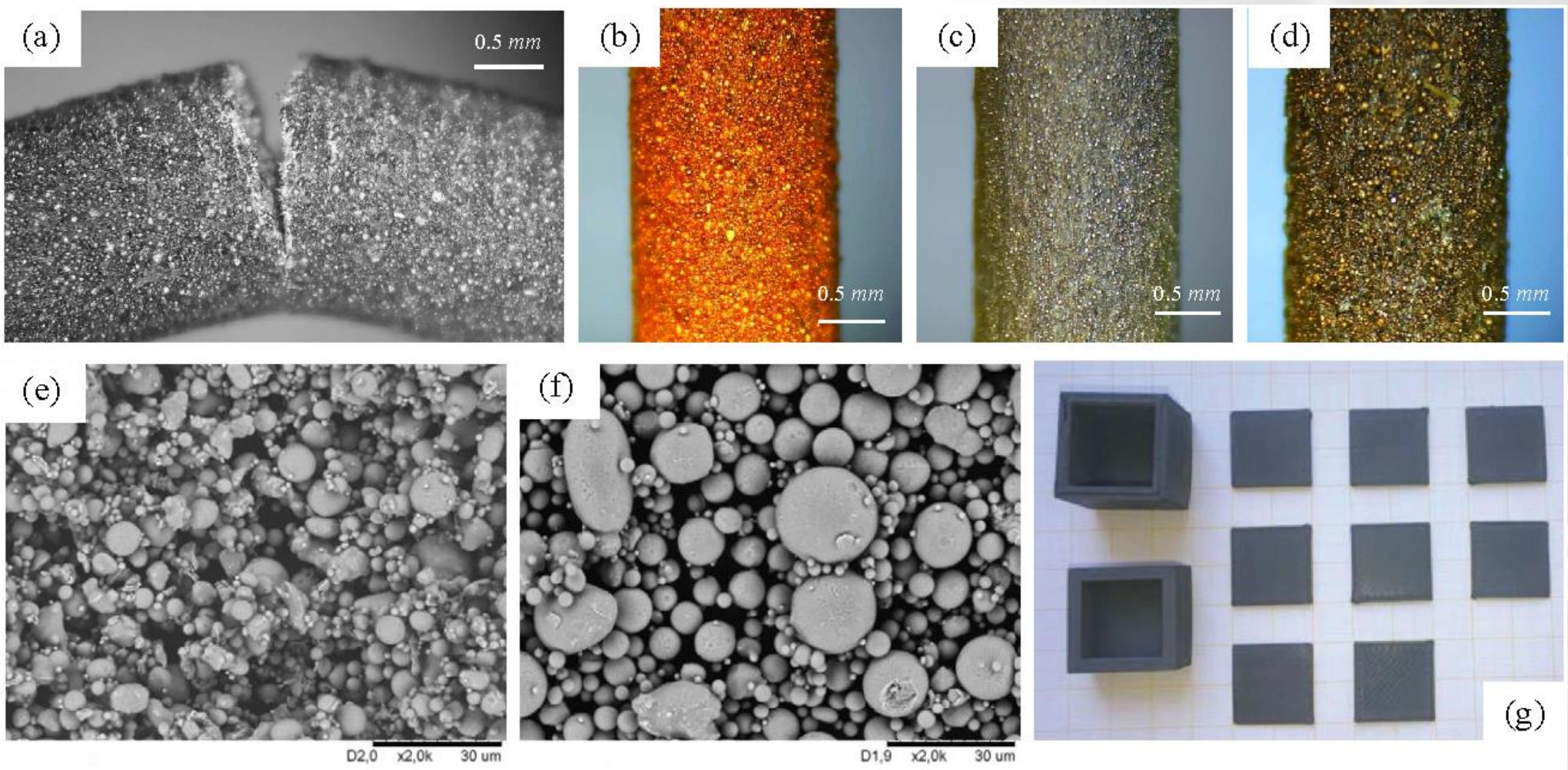
Direct-drive extruder with steel drive gears and feed tube



Pre-heating device

Modified FFF printer

Powder Material Extrusion

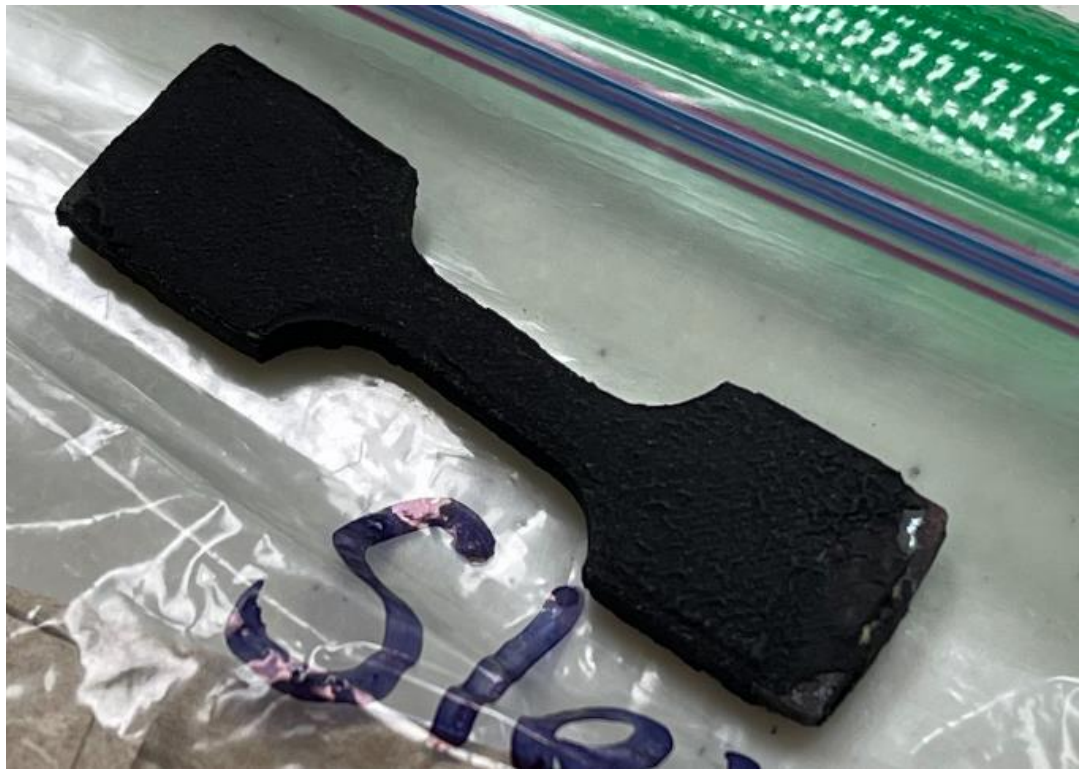


Lotfizarei, Mostafapour, Barari, Jalili, Patterson (2023). Overview of debinding methods for parts manufactured using power material extrusion. Additive Manufacturing, 61: 103335.

Green Parts

Post-Processing

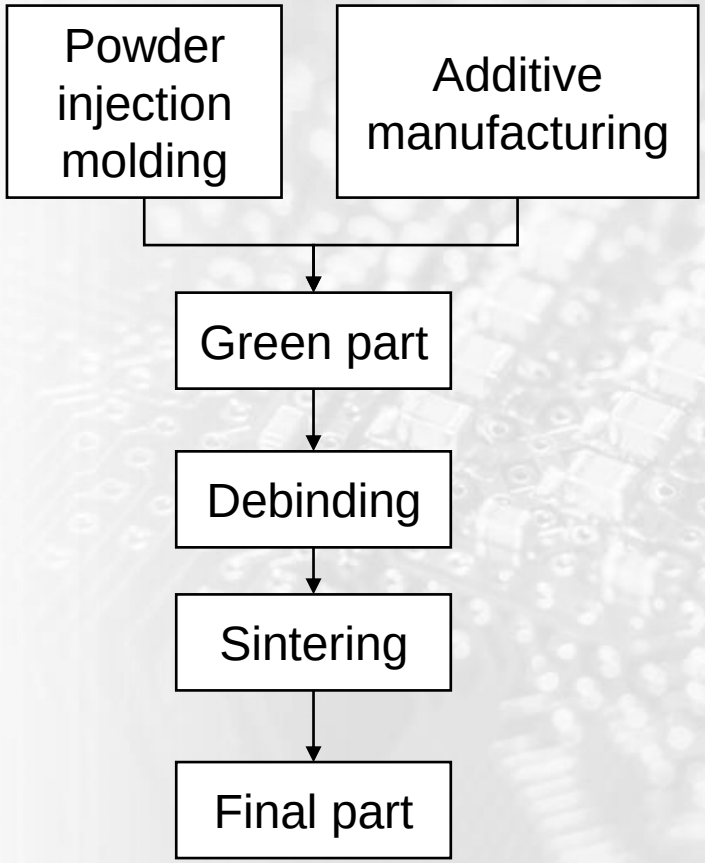
Debinding



Sintering

Manufacturing Considerations

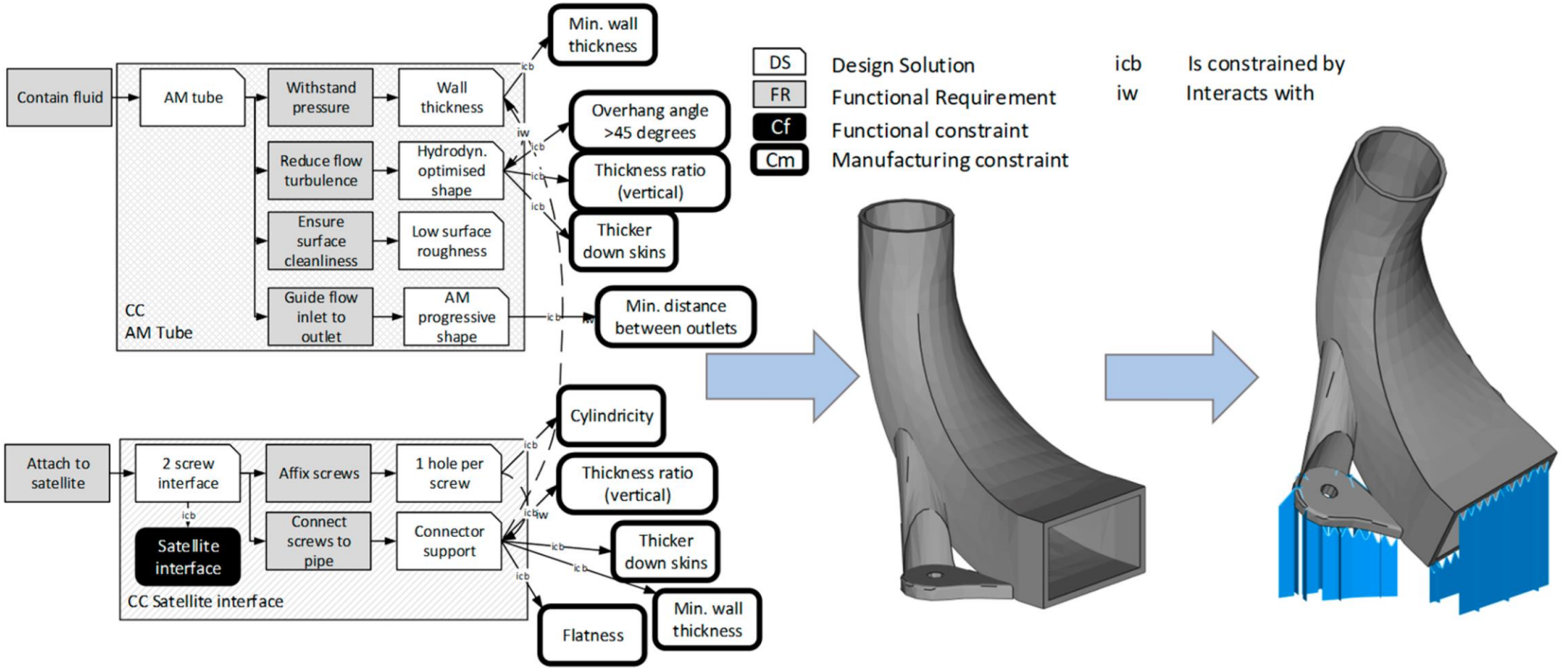
- Process is a mix of powder injection molding and additive manufacturing
- Post-processing is required but removes the need for tooling
- Parts are 93-95% dense after sintering, can be up to 99%+ with HIPS processing
- Even with post-processing, the energy consumption is significantly less than what is seen with PBF processes
- Almost unlimited material freedom, as long as it can be made into a stable powder



Manufacturability Constraints

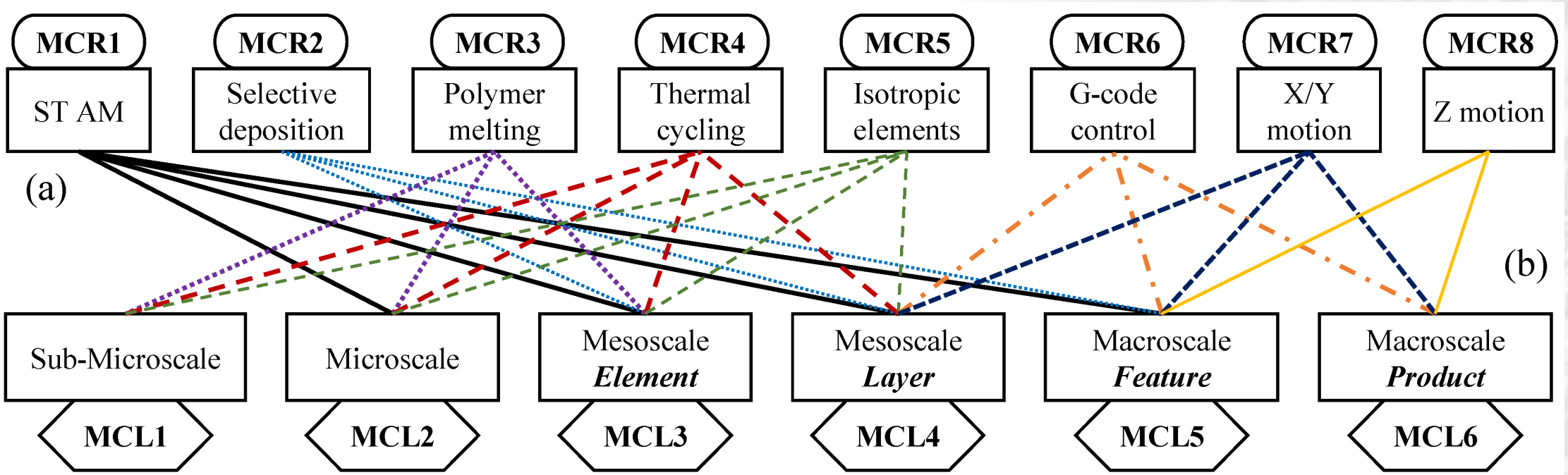
- Standard FFF constraints + powder
  - Combinatorial printing parameters
  - Scanning-type AM process
  - Anisotropic within the layers
  - Powder/binder interactions, uniform distibution
- Post-processing constraints
  - Thermoplastic binder = thermal debinding
  - Sintering, warpage, shrinkage
- Aerospace-specific constraints
  - Light weight
  - Stable at different temperatures and pressures
  - High stress and fatigue resistance
  - Military applications: Entire supply chain in the US

Manufacturability Constraints

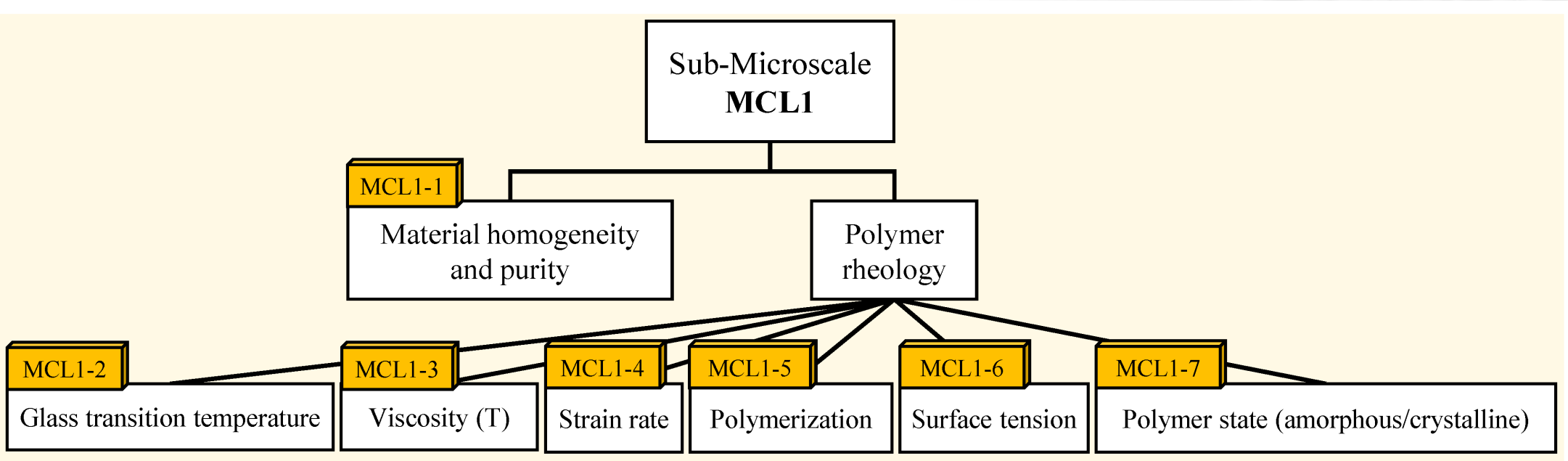


Borgue et al. (2019). Constraint replacement-based design for additive manufacturing of satellite components: Ensuring manufacturability through tailored test artefacts. Aerospace, 6: 124.

Manufacturability Constraints

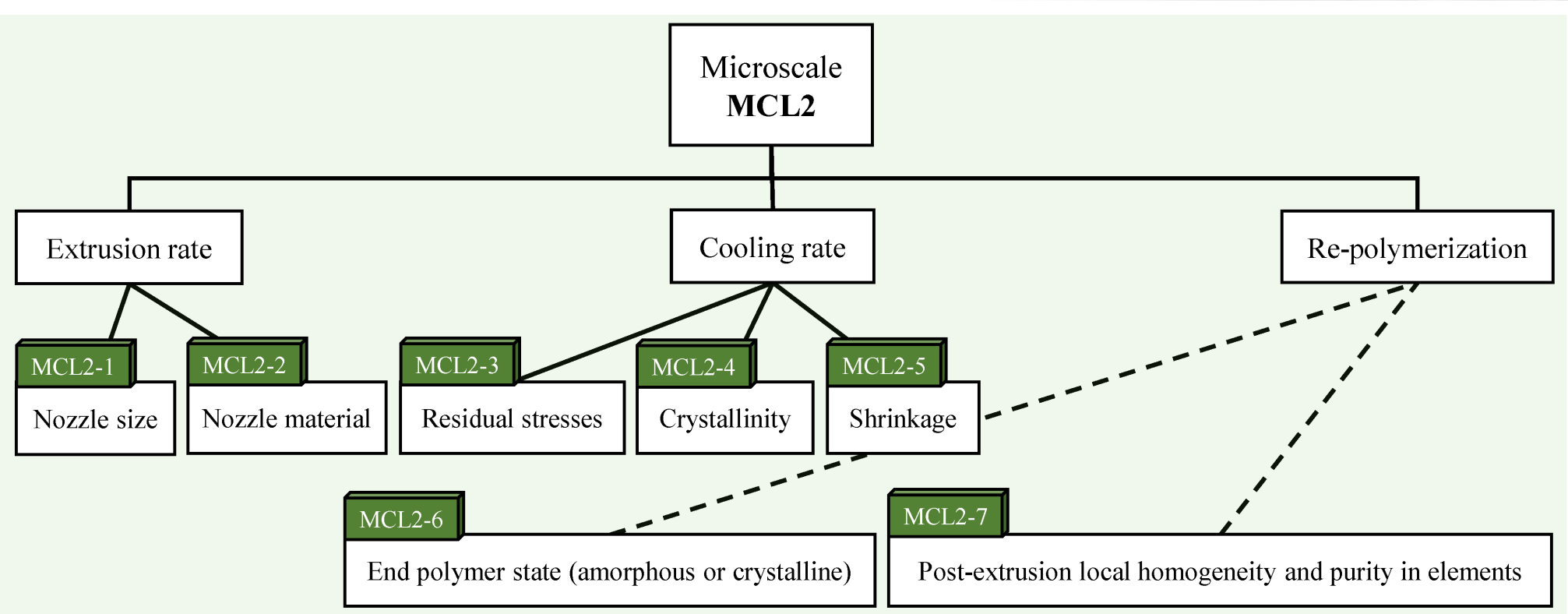


Manufacturability Constraints



Patterson et al. (2021). Identification and mapping of manufacturability constraints for extrusion-based additive manufacturing. Journal of Manufacturing and Materials Processing, 5(2): 33.

Manufacturability Constraints



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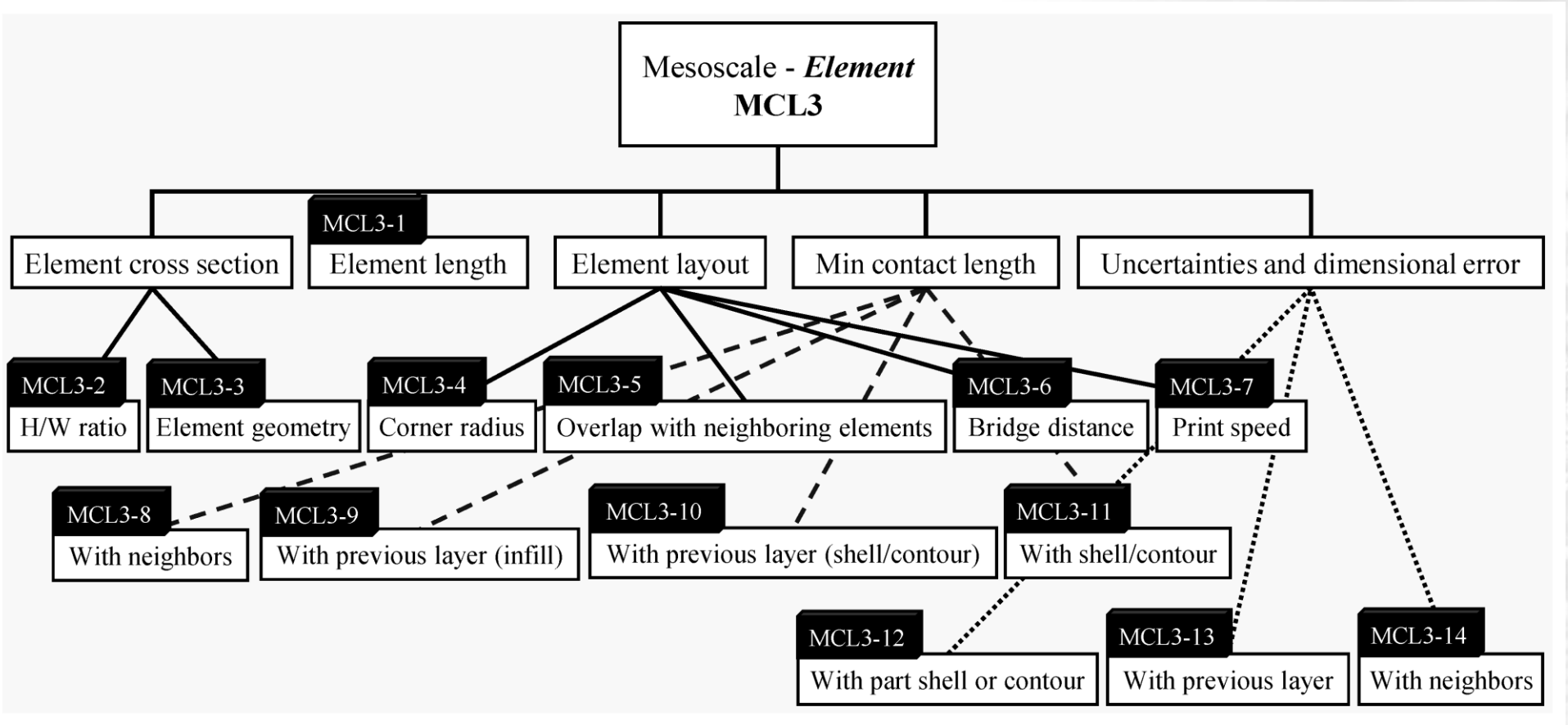

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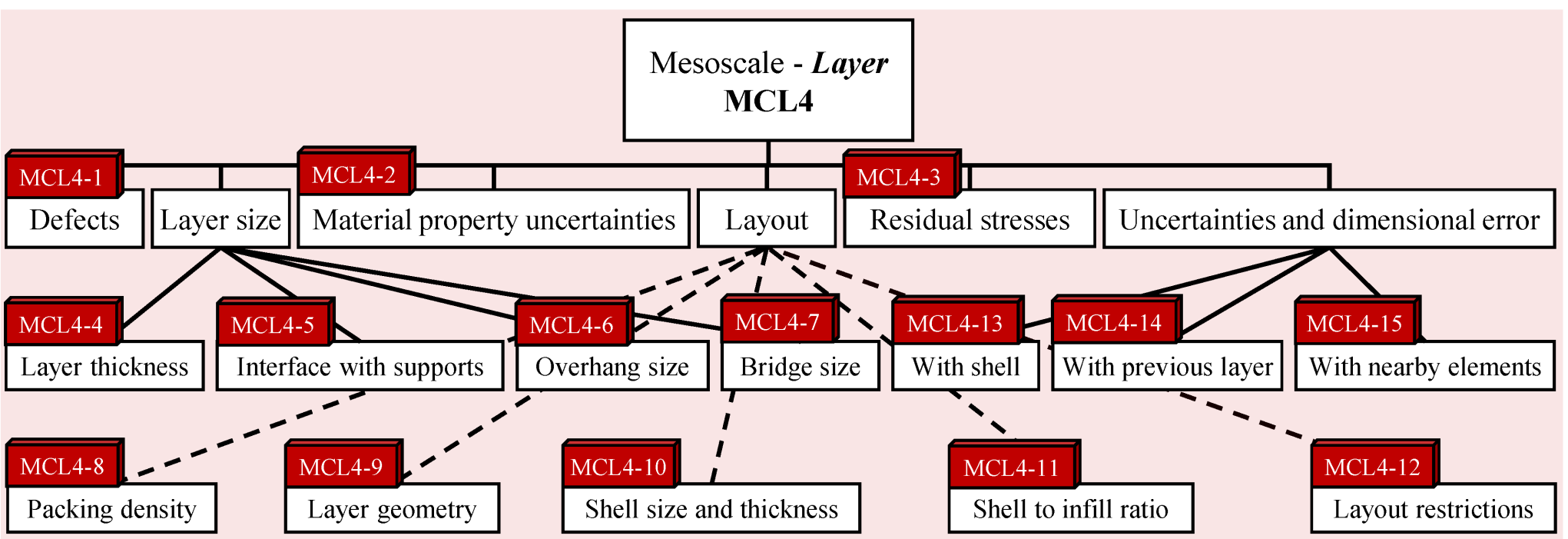

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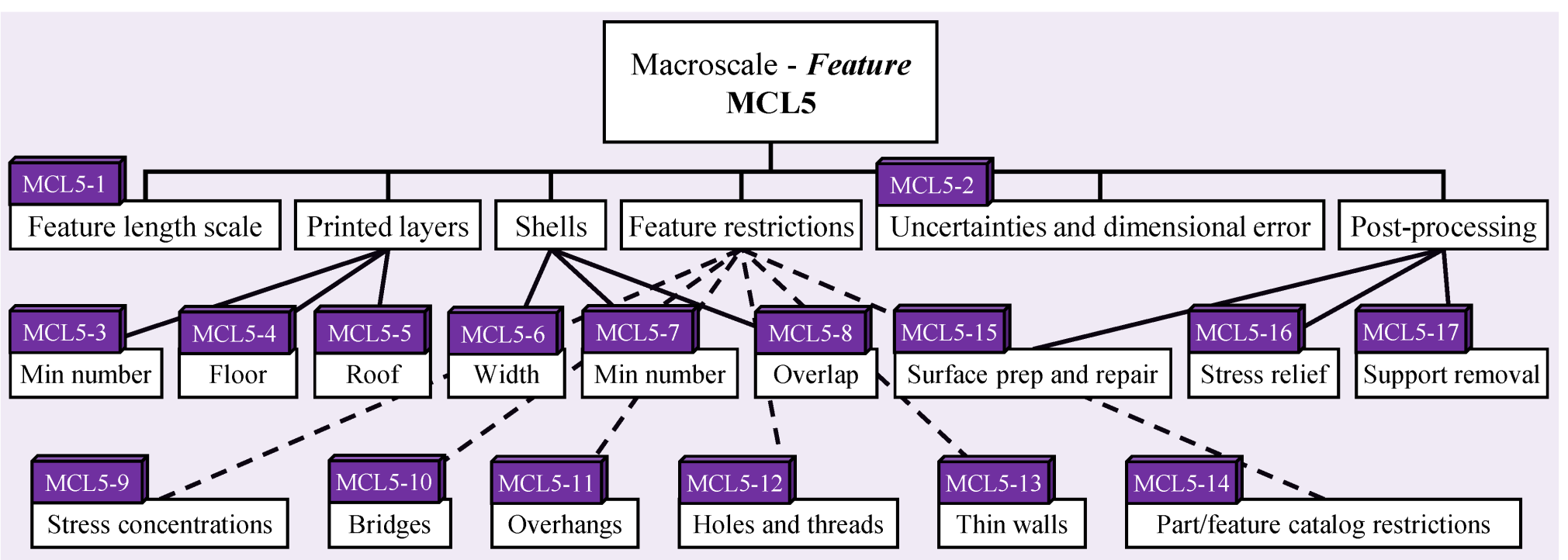

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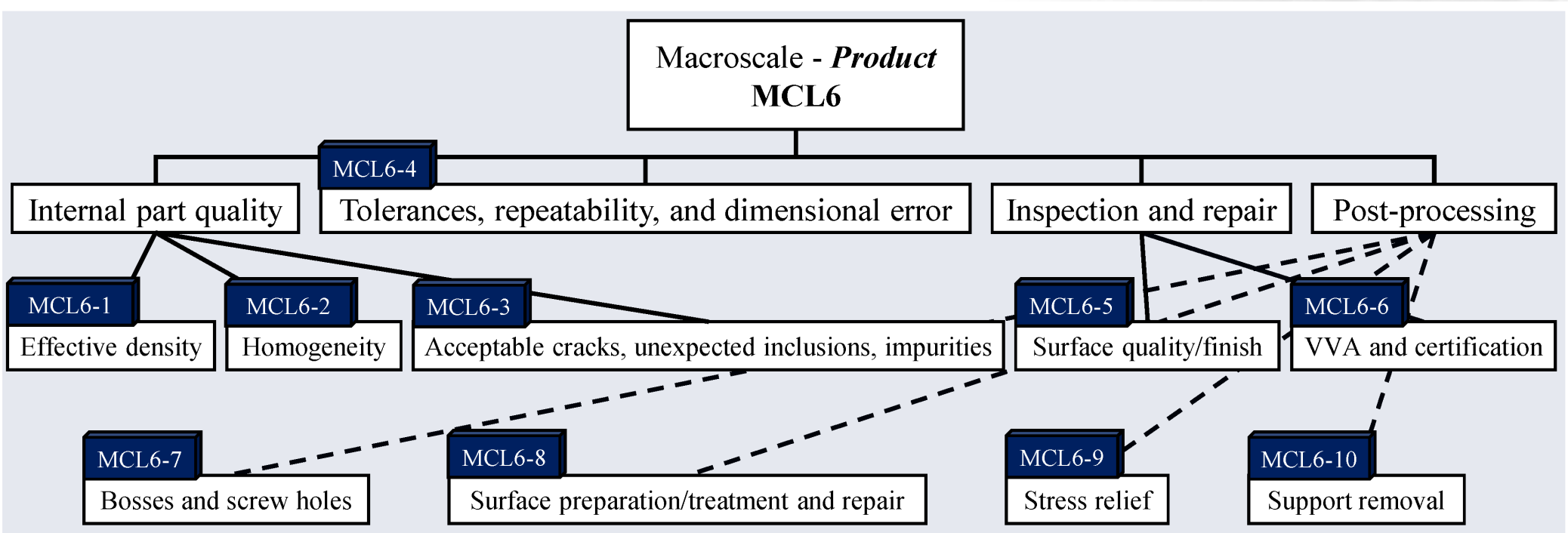

Patterson et al. (2021). Identification and mapping of manufacturability constraints for extrusion-based additive manufacturing. Journal of Manufacturing and Materials Processing, 5(2): 33.

Next Steps

- Formalize a hybrid constraint set for green parts, which consider the needs of debinding and sintering
- Include powder interactions
- Validate theory that binder choice determines print parameters
- Establish % boundary of powder that can be sintered/HIPed into a fully metal part versus particulate composite
- Checklist and full design process
- Design automation
- Explore other materials, particularly cermets
- Explore other thermoplastic binders
- Complete energy use analysis on this process relative to LPBF and other common processes

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