3D PRINTING OF HIGH REFRACTORY ALLOYS FOR AEROSPACE

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Outline

1. Aerospace & Advanced Manufacturing Technologies
2. 3D Printing/Additive manufacturing
3. Refractory alloys for Additive Manufacturing
4. Additive Manufacturing limitations
5. Drawbacks from materials perspective
6. Conclusions

Aerospace & Advanced Manufacturing Technologies

- Aerospace industry - one of the key drivers of Advanced Manufacturing Technologies development
- Aerospace require high duty materials and reliable/mature manufacturing processes
- Aerospace hardware operates in very demanding conditions (stress, temperature, oxidative and/or corrosive environment, etc.)
- R&D activities were carried out from decades to develop/ enable the use of advanced manufacturing technologies and materials
- New materials need qualification and certification to be used in Aerospace – most of advanced technologies still rely on existing certified materials

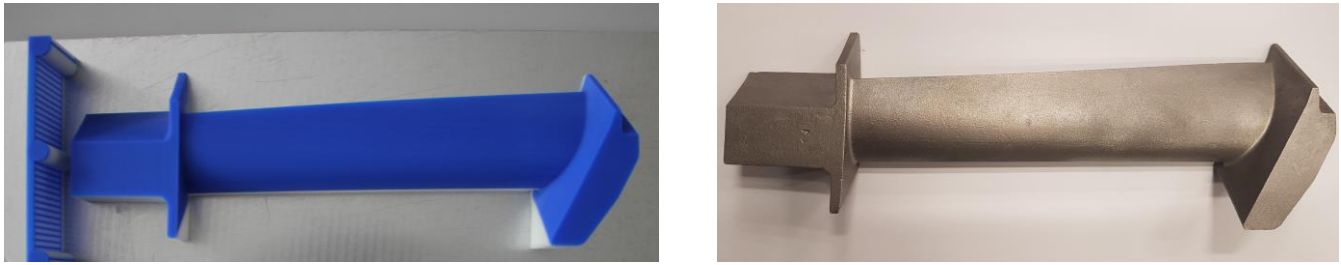
3D Printing/Additive manufacturing

- Several terms and acronyms were used in the last decades for similar processes by users, producers, researchers, media: SLS®, SLM®, DMLS®, EBM®
- Standardization of the terminology used for Additive Manufacturing (AM) Technologies was necessary (ASTM F2792-12)
- Despite of the rapid success of AM of metallic materials, AM is still considered a developing technology – not enough mature for wide use in aerospace industry
- Robust and unified quality control procedures are needed to meet the requirements of aerospace industry for mission-critical applications
- Standards in Aerospace are still being developed for AM parts validation - to further advance, aerospace organizations establish their own guidelines

3D Printing/Additive manufacturing *cont.*

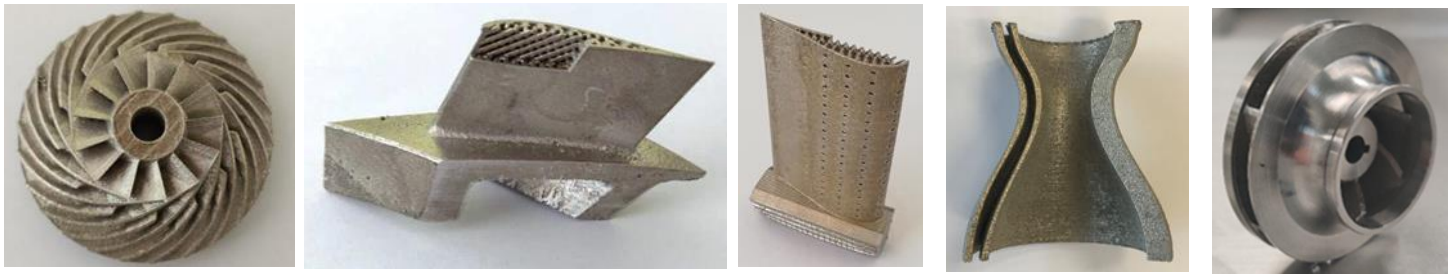
Indirect and **direct** AM processes are used to produce aerospace hardware from high refractory alloys:

Indirect AM processes: wax patterns for investment casting



Wax pattern for investment casting (left) and cast turbine blade (right). *Credit: COMOTI*

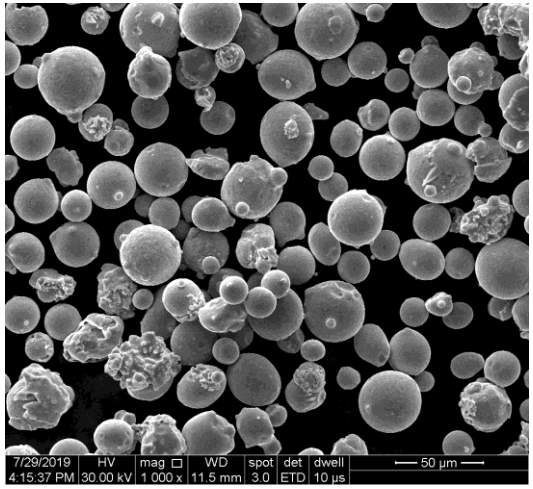
Direct AM processes: 3D printing/Additive manufacturing

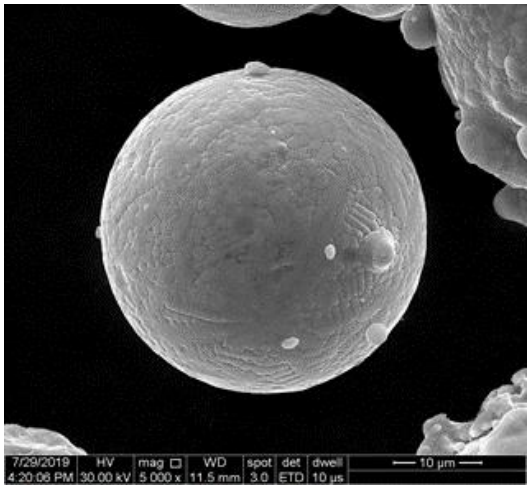


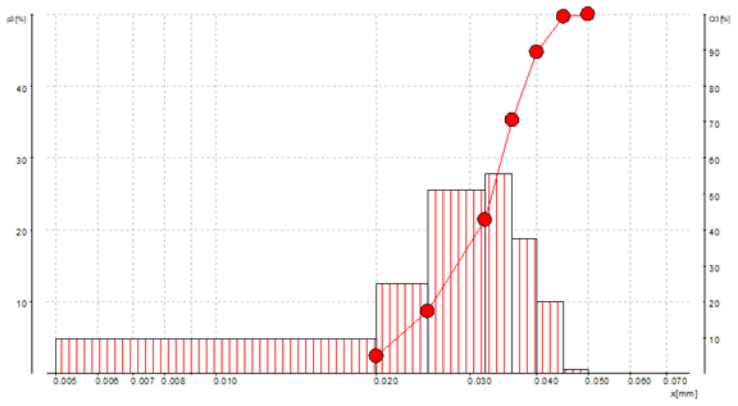
Hardware developed by LPBF in Inconel 625. *Credit: COMOTI*

Refractory alloys for Additive Manufacturing

- A limited number of high refractory alloys metal powder are standardized and qualified for AM (IN 718, IN 625, IN 939, Hastelloy X)
- Other metal powders are used for R&D purposes, including materials initially developed for other processes like single crystal materials (CSMX-4, Nimonic 100, CM247LC, ……)
- Metal powder feedstock requirements: controlled powder size distribution, free of excessive satellites, spherical form without agglomeration and cavities, free of contamination, etc.





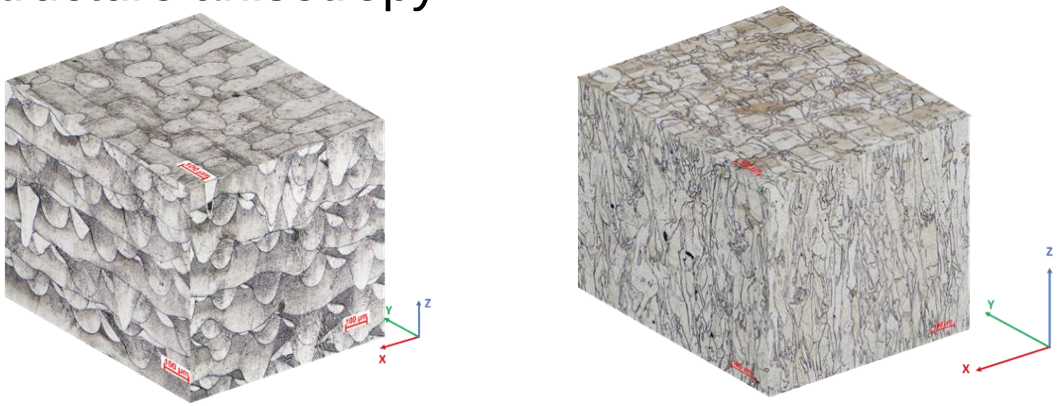


Additive Manufacturing limitations

- Part geometry & orientation in the building volume
- Design limits (successive layers building & part features – internal channels, thin features)
- Manufacturing prioritization: build time, support structures, part distortion
- Thermal build-up (large lasered region in single layer) distortion, residual stresses; thermal distortions lead to geometric inaccuracy
- Printability of certain features (e.g. internal channels, thin features)
- Defects (porosity, balling, lack of fusion, un-melted particles)
- Surface quality (roughness, staircase effect, edge and corner effect)
- Dimensional accuracy
- Post-processing needed (support removal, heat treatment, HIP)

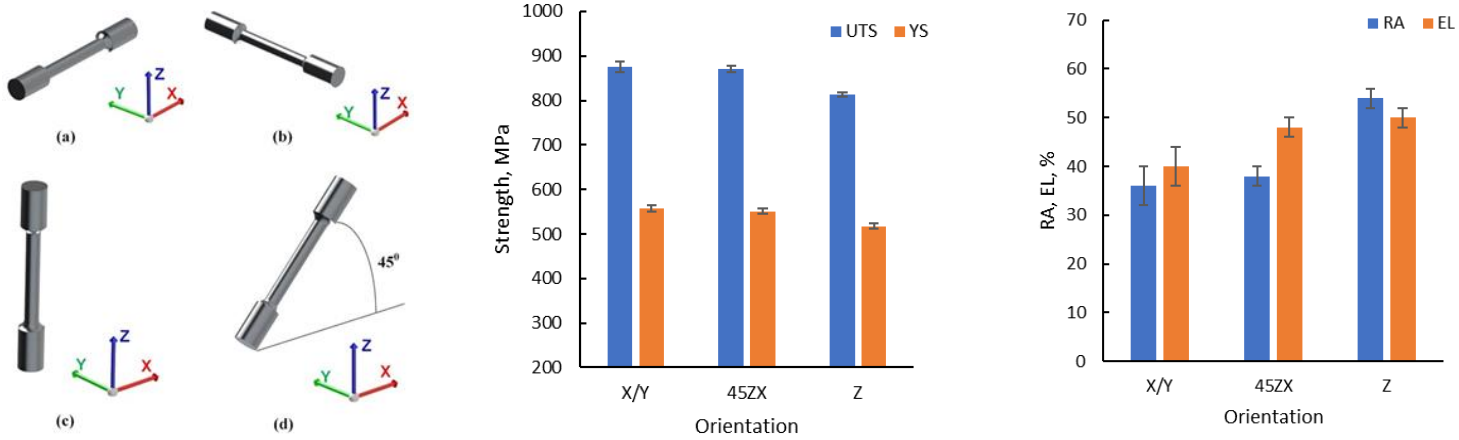
Drawbacks from materials perspective

- Relative density – HIP densification may be required
- Microstructure anisotropy



3D reconstructed microstructure of AM IN 625 in as-built (left) and annealed condition (right). *Credit: COMOTI*

- Mechanical properties anisotropy



Tensile properties anisotropy of AM IN 625 in annealed condition. *Credit: COMOTI*

Conclusions

- Far from being a mature technology, AM is of huge interest in the aerospace industry
- Significant efforts are still required to fully integrate the standards for metal AM
- Qualification and certification (Q&C) procedures are needed for aerospace AM hardware
- Academic, scientific and industrial communities are spending efforts to assess the use of AM to improve and expand the aerospace hardware capabilities

Thank you for your attention!