NRC Technical Assessment of Additive Manufacturing – Laser Powder Bed Fusion

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Outline

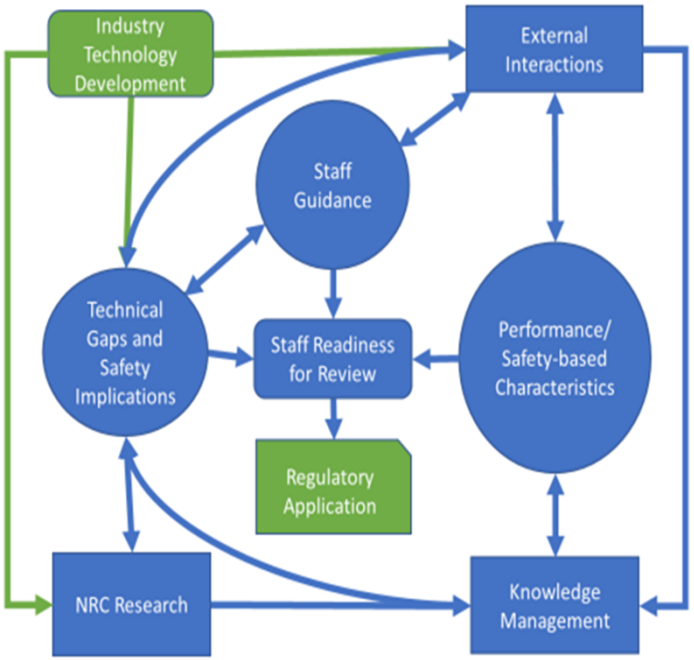
- Background on Advanced Manufacturing
- NRC Technical Assessment – Laser Powder Bed Fusion (LPBF)
  - Background, ranking of significance
  - LPBF Generic Considerations
  - Material Specific Considerations
  - Codes and Standards Gap Assessment
- Conclusions

Advanced Manufacturing Technologies

- Techniques and material processing methods that have **not** been:
  - Traditionally used in the U.S. nuclear industry
  - Formally standardized/codified by the nuclear industry
- NRC Focus based on industry interest
  - Laser Powder Bed Fusion (LPBF)
  - Direct Energy Deposition (DED)
  - Electron Beam (EB) Welding
  - Powder Metallurgy - Hot Isostatic Pressing (PM-HIP)
  - Cold Spray

Action Plan – Rev 1 Tasks

- Task 1 - Technical Preparedness
  - Technical information, knowledge and tools to prepare NRC staff to review AMT applications
- Task 2 - Regulatory Preparedness
  - Regulatory guidance and tools to prepare staff for efficient and effective review of AMT-fabricated components submitted to the NRC for review and approval
- Task 3 - Communications and Knowledge Management
  - Integration of information from external organizations into the NRC staff knowledge base for informed regulatory decision-making
  - External interactions and knowledge sharing, i.e. AMT Workshop



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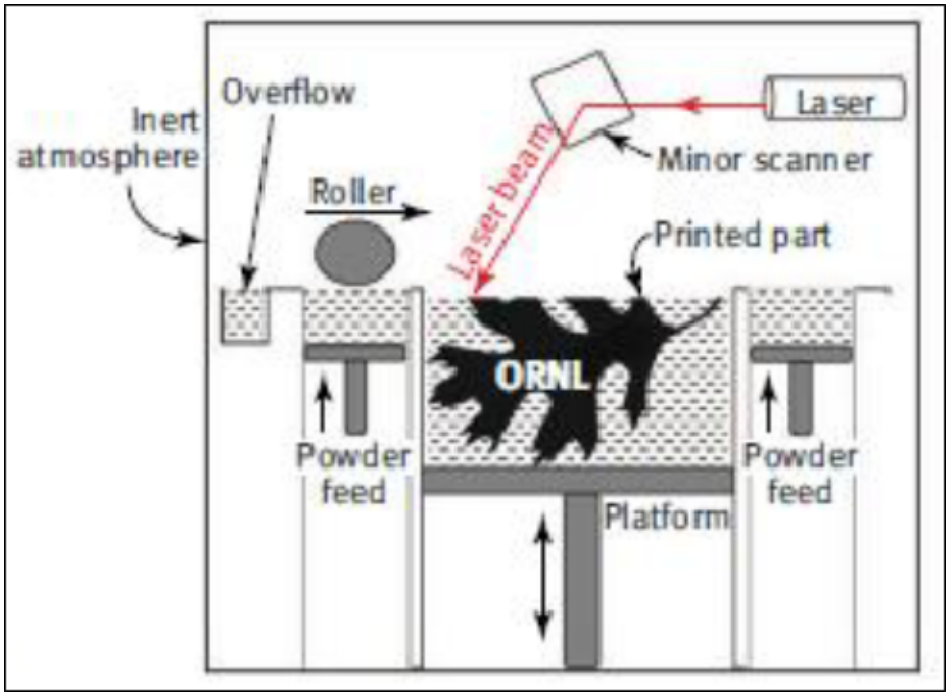
NRC Technical Assessment - LPBF

Laser Powder Bed Fusion

- Process:
  - Uses laser to melt or fuse powder together in bed of powder
  - Generally most advantageous for more complex geometries
- Potential Applications
  - Smaller Class 1, 2 and 3 components, fuel hardware, small internals



https://www.osti.gov/pages/servlets/purl/1437906

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Background

- Based on a technical information and gap assessment written by ORNL for the NRC
- NRC technical assessment provides regulatory perspective and highlights key technical information
- Fulfills the NRC Action Plan Task 1A deliverable to describe:
  - Differences between AMT/conventional component
  - Safety significance of the differences
  - C&S gaps

Ranking of Significance

- Importance – impact on final component performance
  - High – significant impact on component performance
  - Medium – moderate impact on component performance
  - Low – minimal impact on component performance
- Knowledge/Manageability – how well understood and manageable is issue?
- The overall impact to plant safety is a function of component performance and the specific component application

LPBF Generic Differences

Medium Importance

- Machine Process Control
  - **Definition:** Software controlling the scan strategy of the LPBF machine and the machine calibration to reliably fabricate components
  - Manageable with Quality Assurance (QA) including appropriate calibration
- Build Process Management and Control
  - **Definition:** Includes monitoring parameters during fabrication using environmental sensors, in-situ monitoring, and evaluating the effects of build interruptions.
  - Manageable with QA and the use of in situ monitoring and environmental sensor data

Medium Importance

- Witness Specimens
  - **Definition:** Test specimens that are fabricated concurrently with end-use components and used to provide confirmation of build quality and product performance
  - Well established to detect events that may result in component rejection (e.g., delamination)
- Residual Stress
  - **Definition:** Residual stresses form during the LPBF build process and can lead to warping, cracking, and delamination if not properly managed
  - There is significant knowledge on residual stress, including how to manage it through post-processing or NDE

High Importance

- Powder Quality
  - **Definition:** Important characteristics of the powder, such as composition and size distribution, and how it is managed in the production process prior to the build process (e.g., sieving, reuse, storage, contamination).
  - Can be challenging to manage and the effects on final product performance are material specific
- Post - Processing
  - **Definition:** Includes methods used (e.g., HIP, heat treatments) to improve material properties and performance by increasing density and reducing porosity
  - Should make material properties and performance more homogeneous and similar to conventional forged materials
  - Heat treatments are commonly done for LPBF and conventional materials and are fairly well-understood
  - HIP is well-established method but less commonly used for conventional materials where porosity is not a significant issue

High Importance

- Local Geometry Impacts
  - **Definition:** The geometry of the component and the heat transfer characteristics from the product build directly affect local microstructure (e.g., grain size and orientation), which can affect material properties and performance, including SCC susceptibility
  - Can be managed through post-processing and sampling / witness specimens to measure the impacts
- Porosity
  - **Definition:** The size, distribution, and total volume of voids and pores in the LPBF component
  - May have smaller size and higher density than forged materials
  - There is knowledge on how to manage porosity both in the build process and through post-processing

High Importance

- Heterogeneity and Anisotropy
  - **Definition:** Different properties in the build direction due to the nature of the layer-by-layer build process. Impacts the microstructure and generally creates poorer properties between build layers
  - Significant difference from conventional materials and can have a significant impact on product performance if not addressed in the design and fabrication process
  - Generally well-understood but requires specific measures to manage such as sampling methodology or post-processing

Material Specific Differences
316L Stainless Steel

Low Importance

- Tensile Properties
  - Refers to the ultimate tensile and yield strength of the material
  - Not a common failure mode in nuclear components and no more likely in LPBF materials due to their similar or superior tensile properties

Medium Importance

- Fatigue
  - Refers to the initiation and propagation of cracks due to cyclic loading with or without environmental effects playing a significant role in the process.
  - Can lead to component failure, however, it's generally addressed conservatively through design standards and has not generally led to many safety-significant failures or flaws
- Weldability/Joining
  - Refers to the ability to successfully weld a material to another component without unacceptable defects
  - Should not impact component performance if welding Code requirements can be developed

High Importance

- Initial Fracture Toughness
  - Low fracture toughness can lead to brittle component failure
  - Limited data on 316L have shown significantly lower initial fracture toughness depending on post-processing than similar forged materials
- Thermal Aging, SCC and Irradiation Effects
  - Limited data on 316L
  - Representative data is important to demonstrate material behavior
  - Post processing is expected to make material properties and performance similar to conventional forged materials

High Importance

- Weld integrity
  - Refers to the properties and performance of the weld and surrounding heat-affected zone
  - Welds can be a location of degradation and may behave significantly differently with LPBF materials
  - Understanding this behavior is important to inspection and aging management

Codes and Standards Gaps

- Material-specific criteria for powder recycling and sieving
- Assessments of microstructural and material property heterogeneity
  - Should also consider the positive impact of post-processing, such as HIP, on heterogeneity
- Data-driven requirements for number, location and orientations of witness specimens
- Weld integrity and weldability including pre- and post-weld heat treatments

Conclusions

- First of the AMT Technology Assessment and Gap Analysis Reports will be public shortly
  - NRC has developed a companion technical assessment with an NRC perspective that will be made public at the same time
- Additional AMT-specific reports for DED, Cold Spray, EB Welding and PM HIP will be published in 2021