Additive Manufacturing of Nuclear Components and Fuels

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AM at Canadian Nuclear Laboratories

General

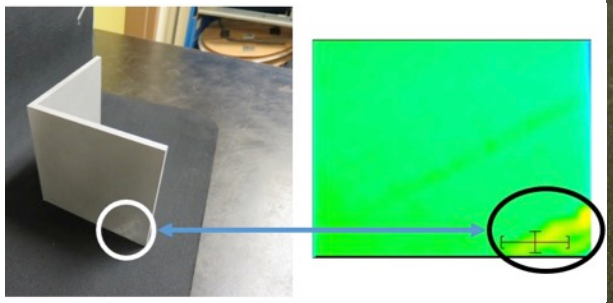
Over the past several years, CNL has been developing its capabilities in the area of Additive Manufacturing (AM) as it is applied to nuclear components and fuels. This has led us to:

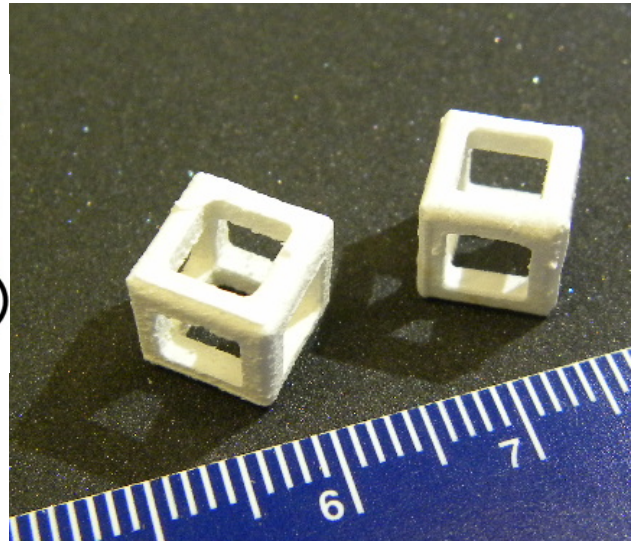
- Technical progress in targeted areas
- Strategic partnerships
- Expanding in-house facilities
- Produce a technology roadmap document to set goals and lay out the path to achieving those goals

AM at Canadian Nuclear Laboratories

Branches of Development

- Metal printing (with a focus on nuclear material)
- Non-destructive examination of AM components
- Printing of nuclear fuel





3D Metal Printing

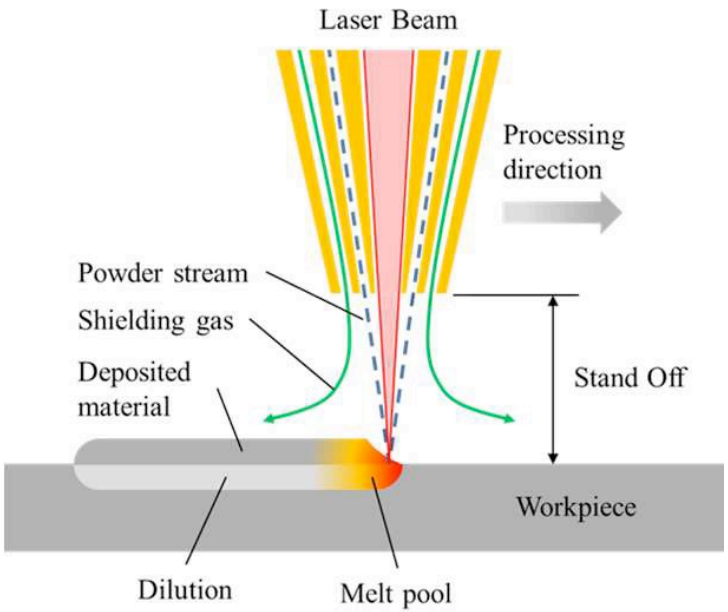
General

- Obviously, there is a great deal of development around the world in the area of 3D metal printing and it doesn't make sense to try to develop expertise in all areas.
- Metal printing is generally achieved using one of two technologies
  - Selective Laser Melting (SLM)
  - Laser Metal Deposition (LMD)

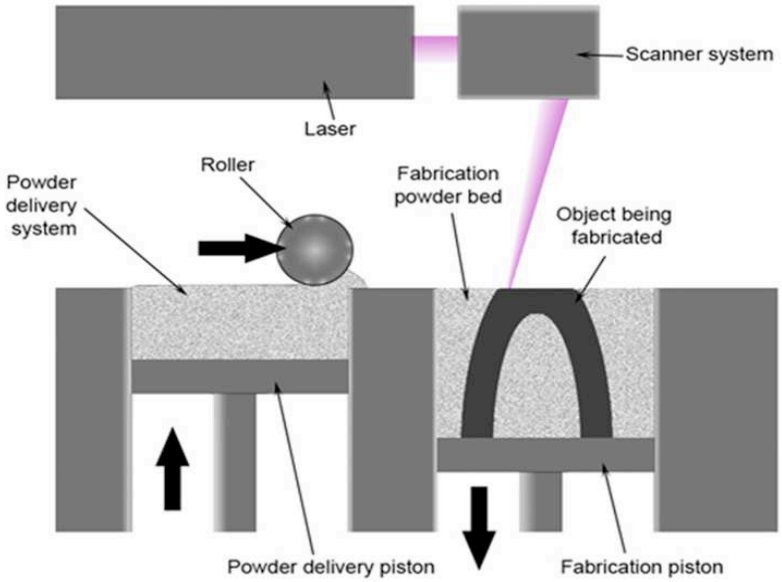
3D Metal Printing

General

- Laser Metal Deposition (LMD)



- Selective Laser Melting (SLM)



3D Metal Printing

General

- Laser Metal Deposition (LMD)
  - Most commonly employed for coatings, cladding, addition of geometry onto existing components but can be used for components depending on geometry
- Selective Laser Melting (SLM)
  - Most commonly employed for printing components
  - Limitations on surface finish
  - Majority of development in the industry is on this technology

3D Metal Printing

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- Development of LMD technology at CNL has primarily focused on the deposition of Zirconium and Zirconium alloys

3D Metal Printing

Collaborations and Partnership

CNL has partnered with select organizations to advance its additive manufacturing knowledge and capabilities. Specifically, CNL has partnered with the University of Waterloo and National Research Council Canada on specific projects related to the deposition of Zirconium on various substrates. CNL is also a proud member of The Welding Institute (TWI) and is working to leverage the work on additive manufacturing that TWI is doing with their partners and members.

3D Metal Printing

Strategic Partnerships - Highlight

- Work with the University of Waterloo was focused on the deposition of Zirconium and investigated the influence of:
  - Powder feed rates
  - Travel speeds
  - Auxiliary shielding gas
  - Shielding gas on cladding contamination
  - Geometry control
- Tests were performed on both as received and recycled metal powder
- Tensile test specimens were cut from deposited material for testing

3D Metal Printing

Strategic Partnerships - Highlight

- A good understanding of the influence of various deposition parameters for Zirconium was gained.
- We were successful in depositing Zirconium and producing solid material that behaved similarly to conventionally-produced solid material.

Material / Powder Type	Orientation and/or location	Young's modulus (GPa)	YS (MPa)	UTS (MPa)	Elongation at UTS (MPa)	YS/UTS	Strain at fracture (%)
Substrate	Rolling	87.3	634	660	7.59%	0.960	13.8
Recycled	C1	93.0	611	731	2.53%	0.836	2.7
Recycled	C2	79.0	-	652	0.99%	-	1.2
Recycled	B	74.4	573	706	7.54%	0.811	8.2
As-received	C1	67.4	569	696	9.90%	0.817	16.3
As-received	C2	83.0	590	750	8.82%	0.787	9.4
As-received	B	88.8	578	718	8.53%	0.805	11.4

3D Metal Printing

Facilities

- In addition to the facilities that CNL has access to through its partners, CNL is establishing its own facilities.
- CNL has two LMD systems that are being installed and commissioned and will allow for rapid development and implementation of AM technology being developed and work to refine and qualify that technology.
- The AM initiatives at CNL are underpinned by well-established materials, chemistry and fuel research facilities and expertise.

3D Metal Printing

Facilities

Commissioning is underway on a laser cladding system that can be used for versatile R&D and the development of techniques to be employed on a full-function commercial system

3D Metal Printing

Facilities

- Procurement is underway for an industrial LMD Printer with the following features:
  - 5 axis CNC motion system
  - 500 x 500 x 500 mm working envelope
  - 2 powder feed units
  - 500W Nd:YAG laser
- The system will have capability to produce parts, but will also provide flexibility for additional development work.

3D Metal Printing

Related Technology Development – NDE of AM components

- To complement CNL's work on additive manufacturing, development related to the non-destructive examination (NDE) of components manufactured by AM is also a focus.
- CNL has expertise in all methods of NDT and is developing ground-breaking technology to allow for in-process monitoring of laser melting using thermographic/infrared methods.

3D Metal Printing

Related Technology Development – NDE of AM components

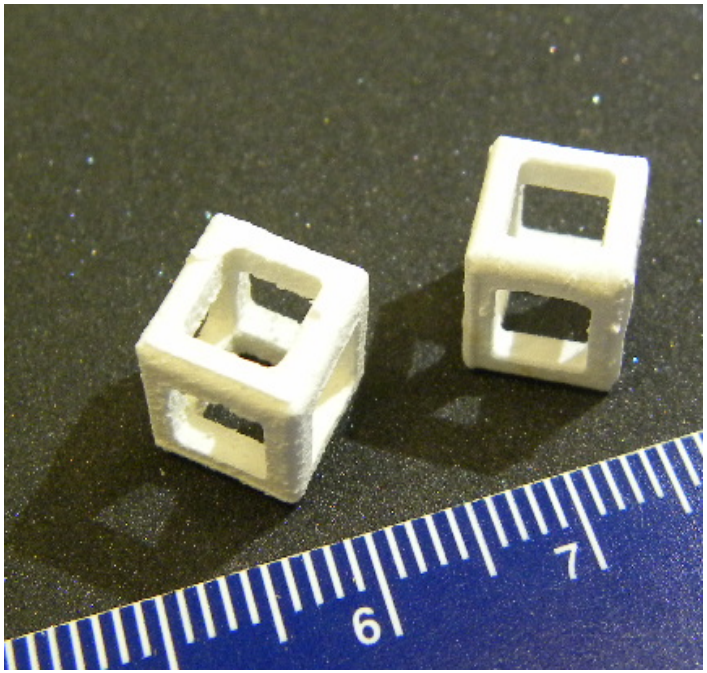
- Two key things change with AM components vs. conventional material that affect the ability to perform NDE:
  - Flaws form through different mechanisms and in different orientations
  - The fundamental NDE parameters (e.g., electrical resistivity for eddy current, speed of sound and acoustic attenuation for ultrasonics) vary with material composition, density, heat treatment history, etc.
- Radiographic methods like high-resolution computerized tomography are most commonly used in industry to inspect AM parts.

Additive Manufacturing of Nuclear Fuel

- CNL has extensive expertise in the area of nuclear fuel development, fabrication and qualification with a full suite of active laboratories and hot cells to examine nuclear fuel.
- CNL believes that AM offers a number of exciting opportunities when applied to nuclear fuel design and fabrication including:
  - Better fuel performance,
  - increased safety margins, and
  - greater accident tolerance

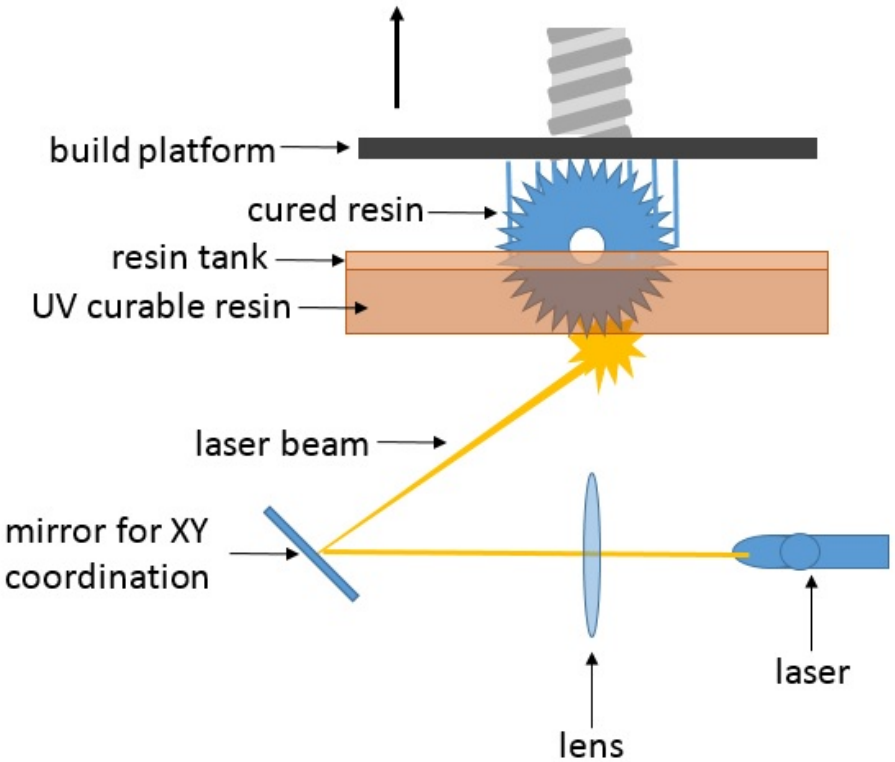
Additive Manufacturing of Nuclear Fuel

- CNL has had success printing ceramic fuel material and work is underway to improve and refine this capability.



Additive Manufacturing of Nuclear Fuel

- Thorium dioxide components were printed on a stereolithography-based 3D printer employing a photopolymer resin
- Technique can be readily extended to a more industrial system



3D Printing

Additive Manufacturing of Nuclear Fuel

- Printing of metallic fuel is also being pursued.
- LMD offers potential improved bonding between the fuel and the cladding and solves a problem with conventional manufacturing methods.
- AM is actually a cheaper option as it replaces several operations and expensive production equipment.