Energetic Material Additive Manufacturing

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REVIEW: *TRADITIONAL MANUFACTURING OF EXPLOSIVES*

The current “state-of-the-art”

Cast-Cure Process

- Cast-Cure
  - Composite materials
    - Polymeric Binders
    - Explosives
    - Metal Fuels
    - Oxidizers
    - Curatives, Catalysts, Bonding Agents…
    - Plasticizers, Antioxidants, Stabilizers…
    - Processing Aids, Ballistic Modifiers

420-Gallon Mixer
Cap: 7,000 Pounds

Melt-Cast Process

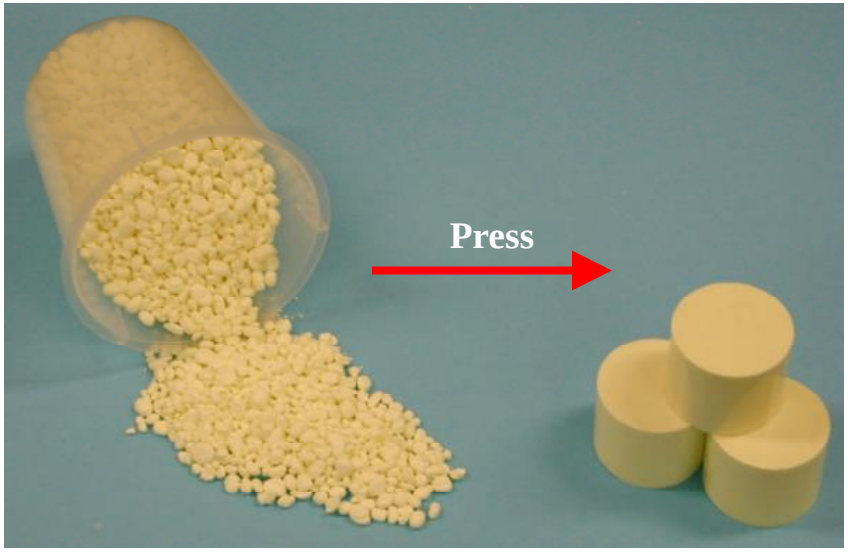
- Melt-Cast
  - Purse explosive melted in steam jacketed kettle
  - Charges are loaded by one of three main techniques:
    - Straight pour
    - Pellet Load
    - Riser Load


1,200 lb Struthers-Wells Kettle


600 lb Groen Kettles

Pressed Powder Process

- Pressed Powders
  - Produce a “molding” powder
    - Explosive Molecules
    - Wax or Plastic Binder
    - Solvent
  - Press the powder into require shape or into case



Reactor Vessel
200 lbs Powder

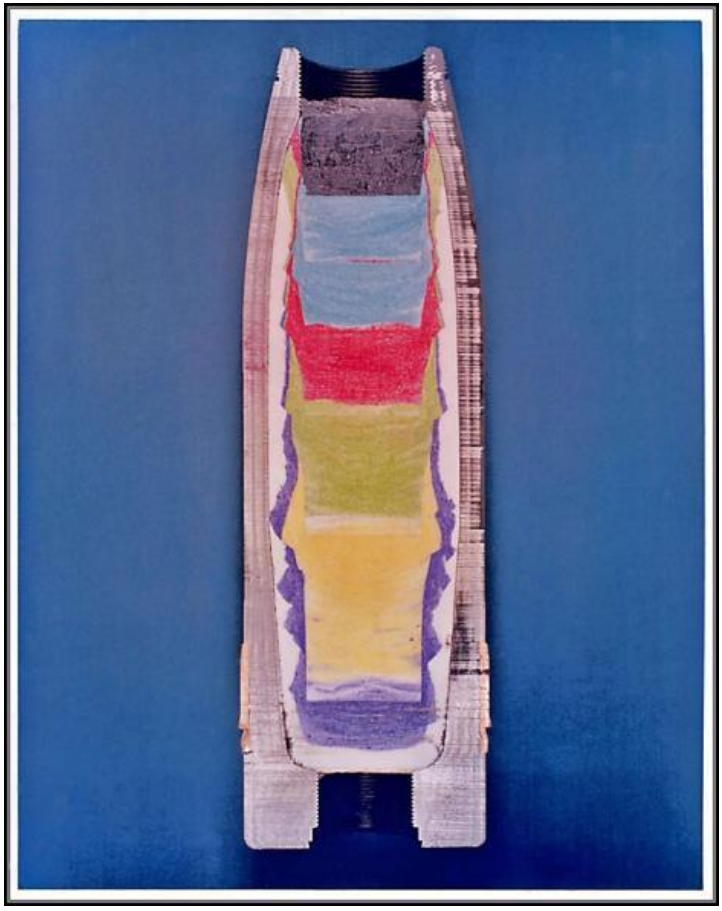
300 ton Press

Problems with Traditional Manufacturing of Explosives

- Cast-Cure
  - Settling of ingredients
  - Poor bonding of cast material to casing
  - Shrinkage and cracking
- Melt-Cast
  - Shrinkage and cracking
  - Irreversible growth
  - TNT based explosives are poor in cook-off scenarios
- Pressed
  - Not suitable for very large munitions
  - Not suitable for munitions with limited access, internal plumbing, unusual shapes

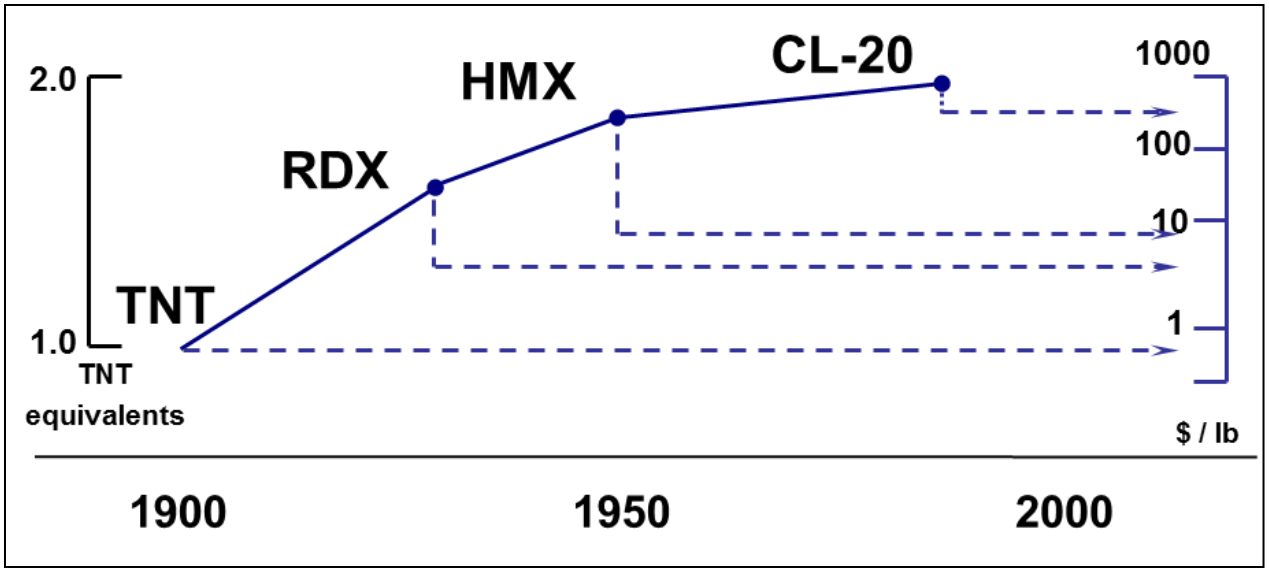
Need for Disruptive Technologies

- Traditional explosive manufacturing
  - Formulations limited to production via:
    - Cast-Cure
    - Melt-Cast
    - Pressed Powders
  - Limited set of ingredients.
  - Feedstock sources limited, often single vendor or foreign sourced
- Improvements to existing technologies
  - often incremental only, difficult/costly to update large scale manufacturing plants
  - limited impact on performance or munition safety



5”/58 Projectile Showing Incremental Pressing of Explosive Fill

Need for Disruptive Technologies



- After 100 years of explosive molecule synthesis efforts…
  - We have 2x TNT with a significant cost increase per pound
  - CL-20, the top molecule, is qualified in only one DoD formulation
    - CL-20 adoption is held back by
      - Money/Time to redevelop formulations for existing systems
      - Lack of production of the molecule (economy of scale).
    - The one formulation…? An explosive ink used in 3D printing of fuzes.

Introducing Additive Manufacturing (AM)

- Additive Manufacturing, a working definition
  - A general term that encompasses several technologies that can create 3D objects by adding material layer by layer
- General Benefits
  - Cost Savings
  - Material Control
  - Rapid Prototyping

Why Energetic Material AM?

- Cost Savings
  - AM cost per part insensitive to number of parts produced

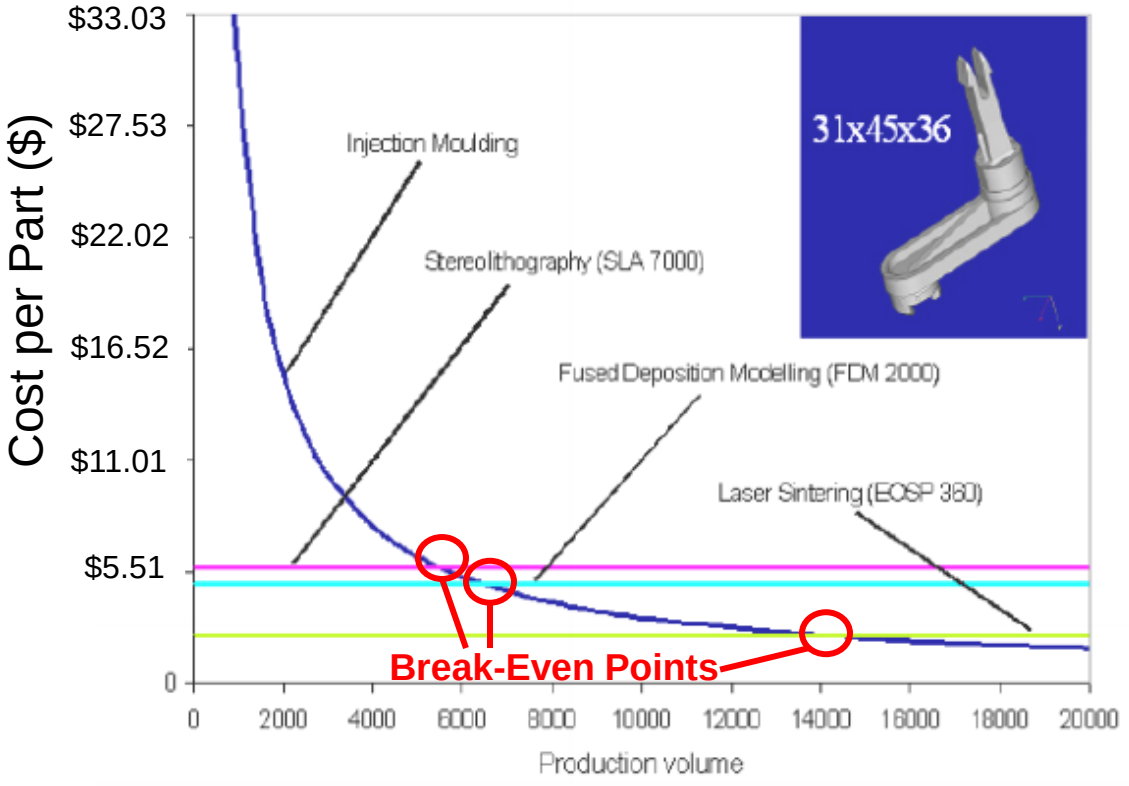
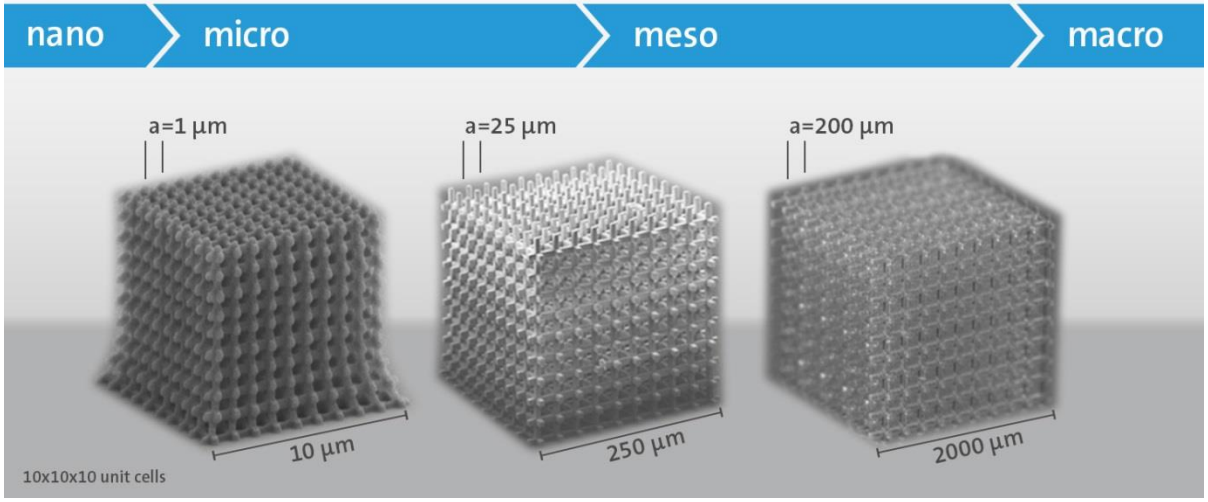


Figure 7 - Comparison of several AM methods to Injection Molding - Rapid Manufacturing Research Group at Loughborough University (UK) Study

Why Energetic Material AM?



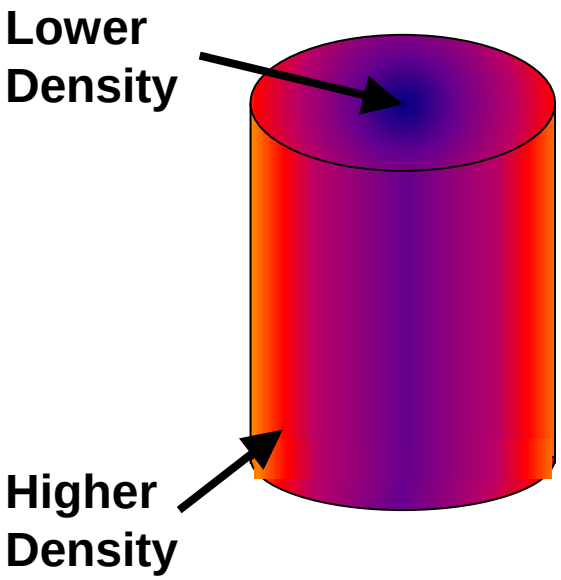
http://www.nanoscribe.de/en/technology/additive-manufacturing/

- Precision Placement of Materials
  - Unique structures not obtainable by traditional means
  - Reduced waste

Why Energetic Material AM?

- Composition/Density Control
  - Gradients can produce unique explosive effects
    - Detonation Merging, multi-point initiation “baked in”, insensitivity, etc.

Radially Density Graded Energetic



Compositional Gradients

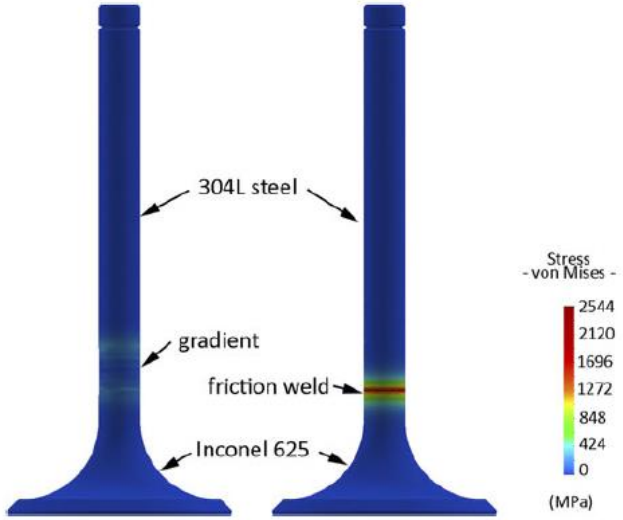
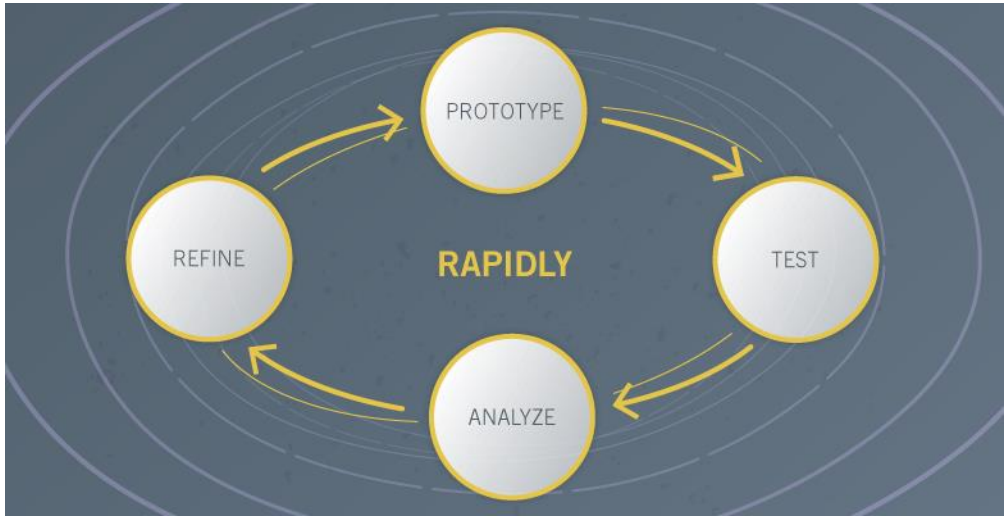


FIG. 5. A finite element model showing elastic mismatch in two dissimilar metal automobile valve stems at 1000 K. The figure on the left shows a valve with a 304L stainless steel stem connected to an Inconel 625 valve via a 2.5 cm long gradient of composition. On the right, the gradient is replaced with a friction weld. The stress at the joint of the friction welded part has an approximately ten times higher stress than the compositionally graded alloy.

Source: J. Mater. Res., Vol. 29, No. 17, Sep 14, 2014

Why Energetic Material AM?

- Rapid Prototyping
  - Reduce time between design and a working prototype
  - Can incorporate cost savings and material controls



http://www.bresslergroup.com/blog/rapid-prototyping-for-user-research/

Technology Gap: Polymer Solutions

- Gap
  - Compatibility of existing energetics with current feedstock for material extruded systems
- Need to develop AM compatible melt-castable and cast-curable energetic binders for usage in Extruder 3D printers

Current COTS Range of Extruded Polymers

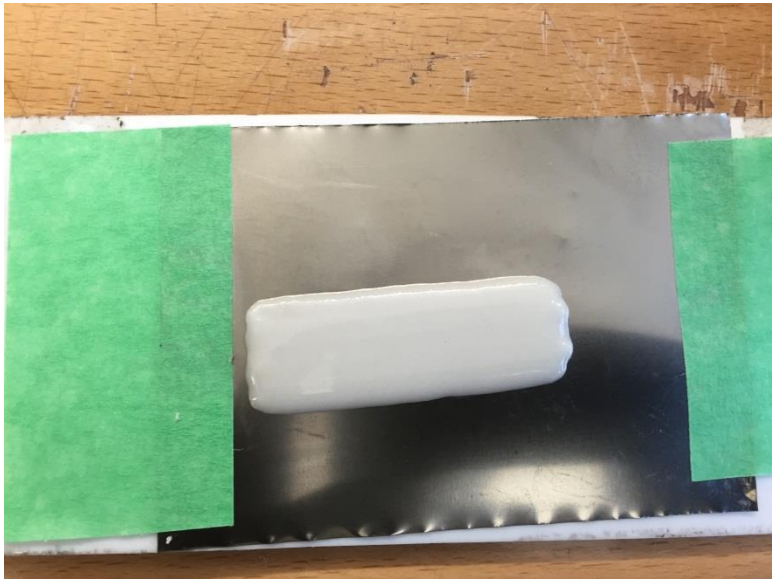
We need to expand upon the very limited list of thermal plastics/polymers to produce energetic materials

Near Term R&D Efforts at IHEODTD

- AM compatible binders
  - Leverage existing programs to acquire COTS material extruder style printer
  - Survey existing melt/cure-castable binders for use in energetic formulations
  - Demonstrate AM compatibility with promising binders with and without inert simulant
  - Develop Safe handling procedures
  - Produce small-scale explosive test samples with down-selected binder in 3-D printer
  - Identified academic partners already making good progress in these areas

- Functional Graded Materials
  - Leverage existing programs to acquire COTS, multi-nozzle, material (ink) jet printer
    - select promising formulations that would be applicable to density and compositional grading – ex. Lakehurst fire suppression
  - Demonstrate Successful FGM characteristics and microstructural control

AM printed PBX Simulants



- AM Produced PBX Simulant
  - R45M Binder (HTPB based)
  - 88% bi-modal sized solids loading
  - Produced in collaboration with SDSMT

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QUESTIONS?

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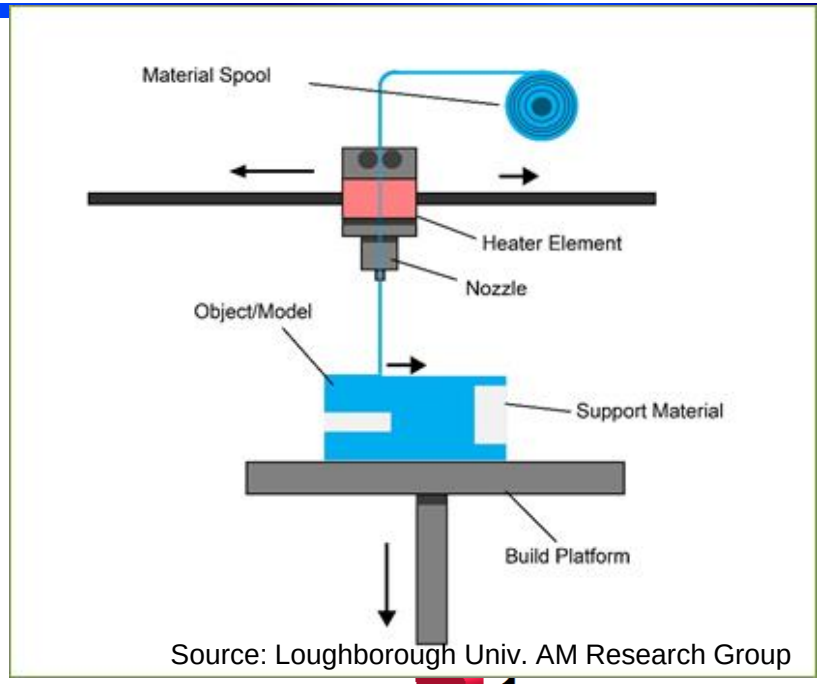
Back-up Slides

AM Technologies

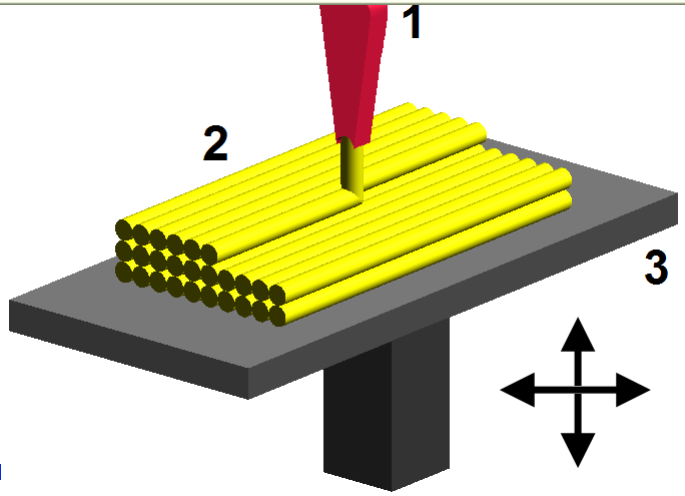
- Material Extrusion
  - Material selectively dispensed through a nozzle
  - Inexpensive, most common AM technology
  - Resolution limited by nozzle radius

Most Common Form:

- Fused Deposition Modeling (FDM)
  - Plastic or metal filaments as feedstock.
  - Many commercial vendors
    - Stratsys, 3DSystems, etc.
  - Used at the CRIP
  - Requires post processing



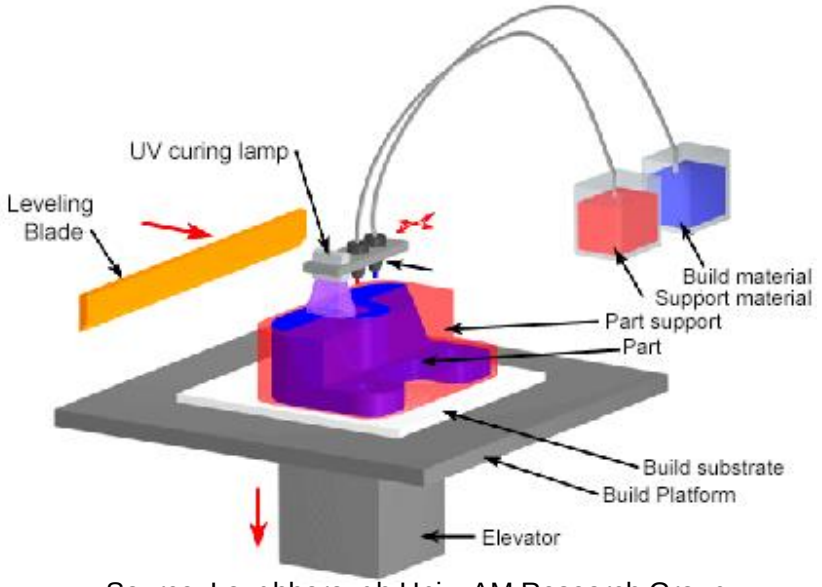
Source: Loughborough Univ. AM Research Group



Source: Wikipedia

AM Technologies

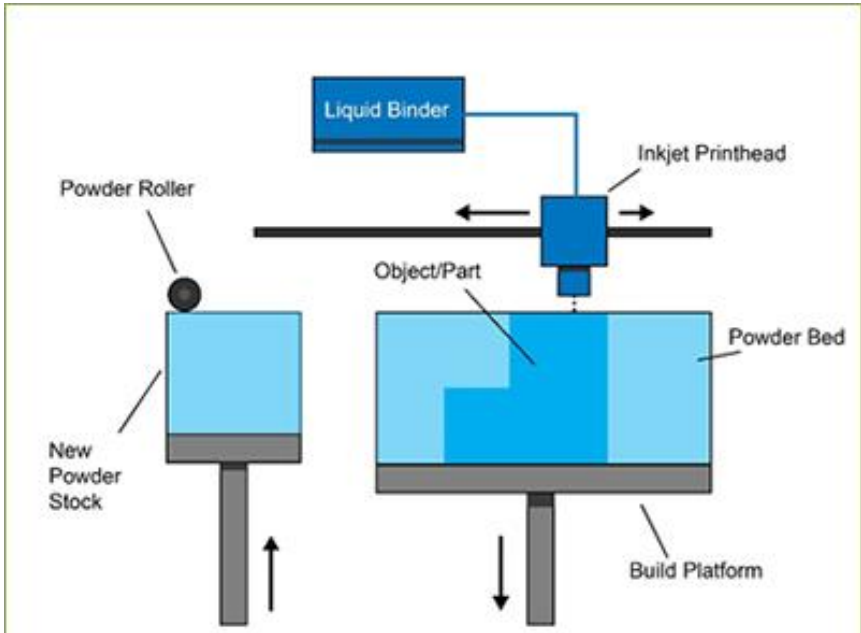
- Material Jetting
  - Photopolymer droplets selectively deposited and UV cured
  - Multiple print heads can simultaneously produces multiple materials in final product
    - PolyJet Connex3 system has 82 Heads for 82 different materials.
  - High accuracy and resolution
  - Limited to photopolymers and some waxes



Source: Loughborough Univ. AM Research Group

AM Technologies

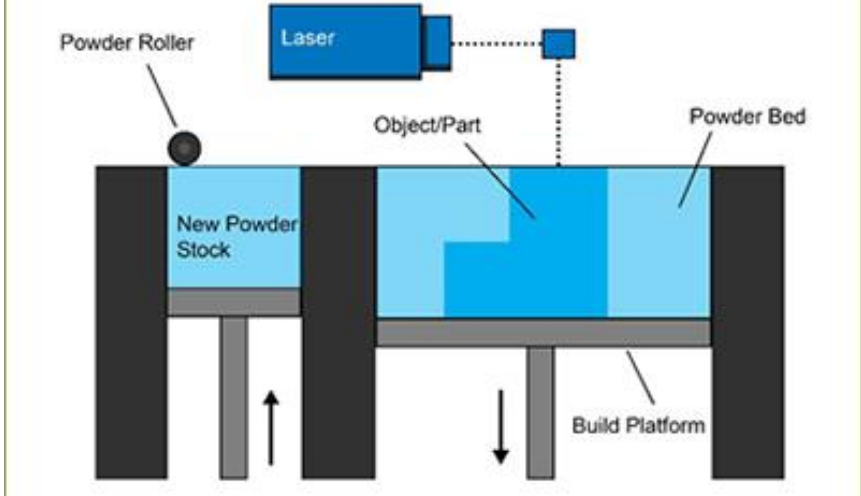
- Binder Jetting
  - Liquid binder is selectively deposited to bind powder/granular materials into a structure.
  - Wide range of materials: metals, powders, and ceramics
  - High speed, but not good for structural parts
  - Post-processing required for hardening
  - Example of Binder Jetting



Source: Loughborough Univ. AM Research Group

AM Technologies

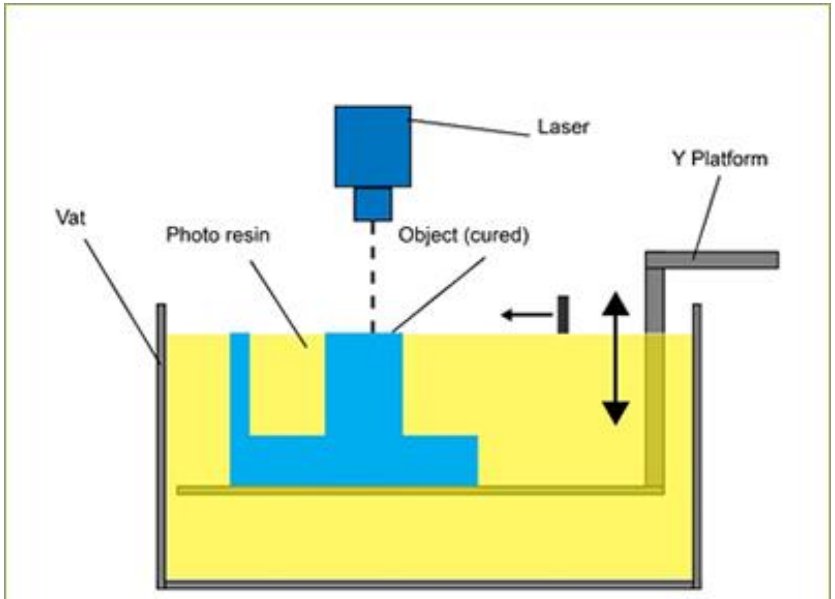
- Powder Bed Fusion
  - Thermal energy selectively fuses regions of a powder bed
  - Uses a laser or electron beam
  - Can use metals or polymer powders
  - Inexpensive, but slow
  - Examples
    - Direct Metal Laser Sintering (DMLS)
    - Electron Beam Melting (EBM)
    - Selective Heat Sintering (SHS)
    - Selective Laser Melting (SLM)
    - Selective Laser Sintering (SLS)



Source: Loughborough Univ. AM Research Group

AM Technologies

- Vat Photopolymerization
  - Liquid Photopolymer in a vat is selectively cured by light
  - High print accuracy
  - Fast
  - Limited material range (photo-resins)
  - Novel: Continuous Liquid Interface Production (CLIP)
    - CLIP Video



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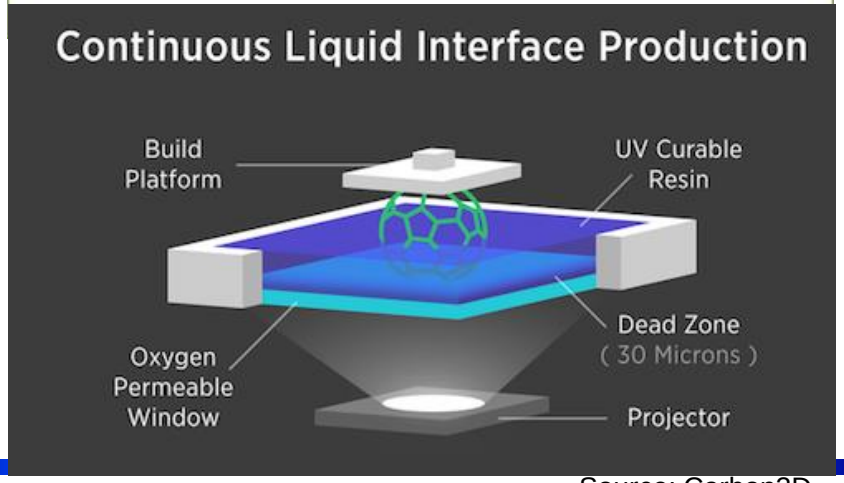
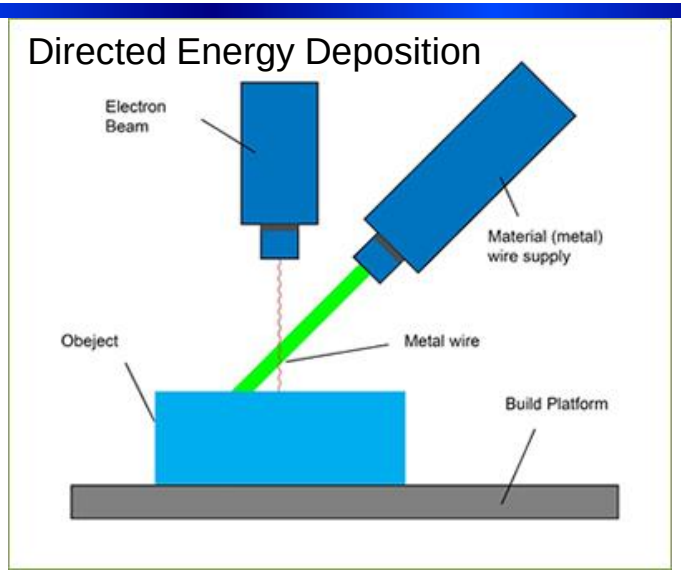


Source: Carbon3D

Other AM Technologies

- Directed Energy Deposition
  - Thermal energy fuses materials by melting as they are being deposited
  - Limited to metals

- Sheet Lamination
  - Sheets of material bonded to form an object.
  - Limited to Paper, Plastics, some sheet metals



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