

# Additive Manufacturing

**GVSETS**

GROUND VEHICLE SYSTEMS ENGINEERING & TECHNOLOGY SYMPOSIUM  
& ADVANCED PLANNING BRIEFING FOR INDUSTRY



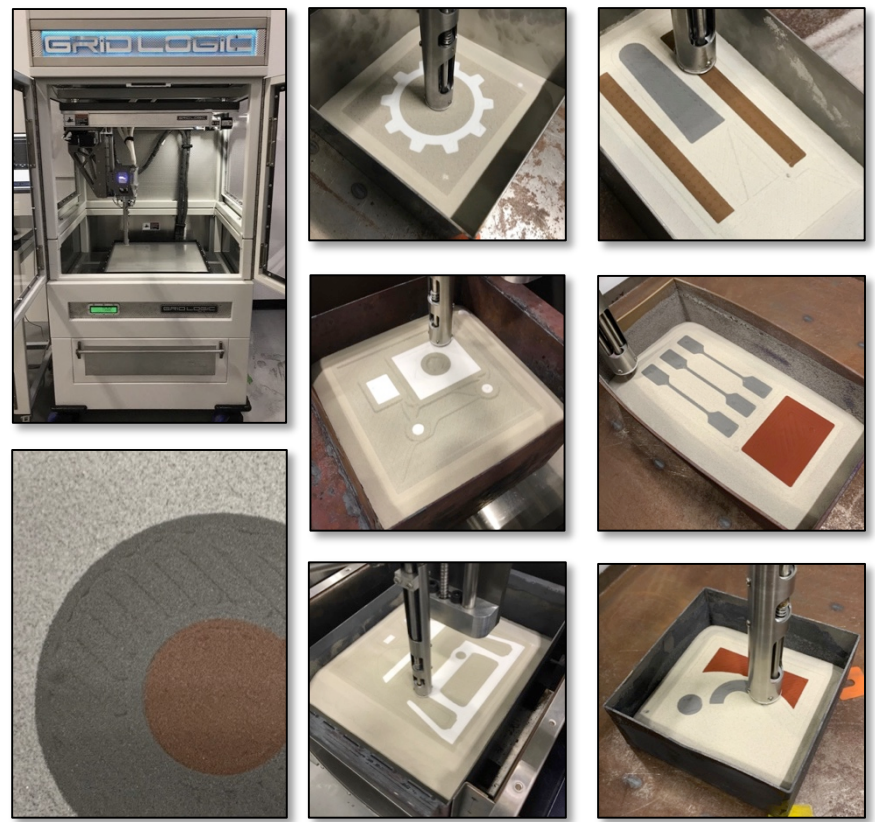
**NDIA**  
Michigan

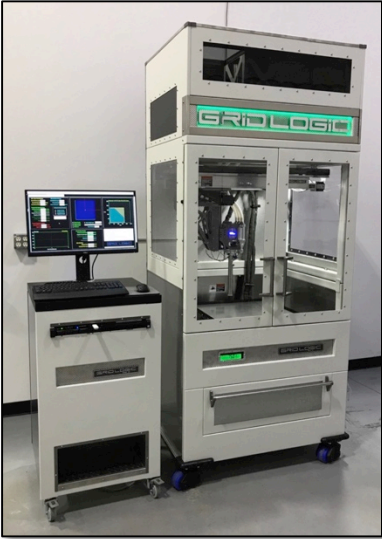
## **Ordered Powder Lithography: A Multi-Material Additive Manufacturing Technology**

Matthew Holcomb  
Grid Logic, Lapeer, MI



- Multi-material 3D Printing of Powders
  - Self-leveling powder print head
  - No powder bed
  - Efficient use of expensive powder
  - Open-air operation
  - Binders not needed
- Bulk Processing
  - Thermal processing of entire build cartridge
  - Selective consolidation of one or more materials





- GL-250
  - 3 powder print head
    - 0.08” nozzle ID
  - Max Build: 10”x10”x 8”
  - Capacity: 44 lbs.

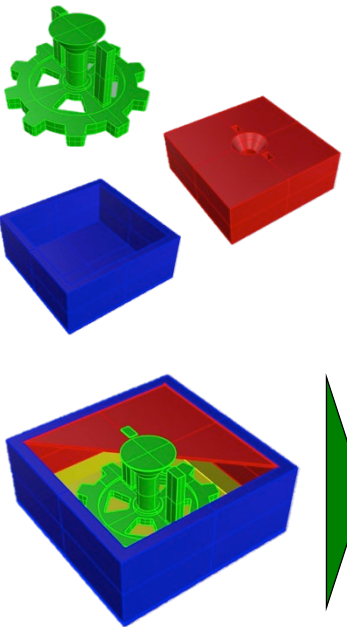


- GL-450
  - 3 powder print head
    - 0.12” nozzle ID
  - Max Build: 18”x18”x12”
  - Capacity: 175 lbs.

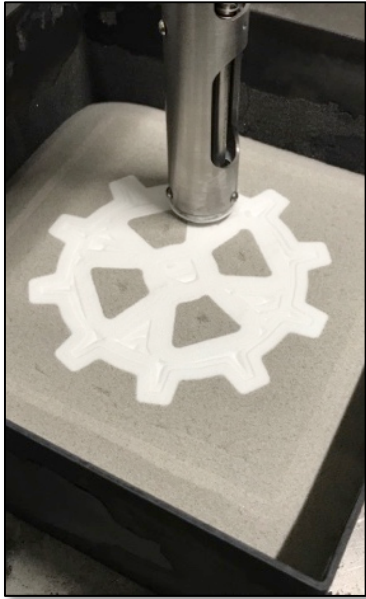
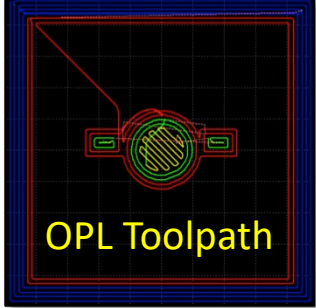
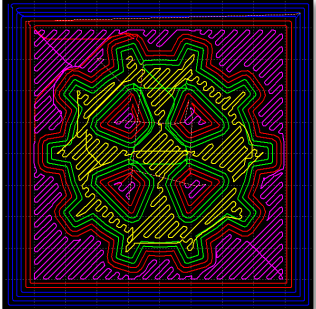
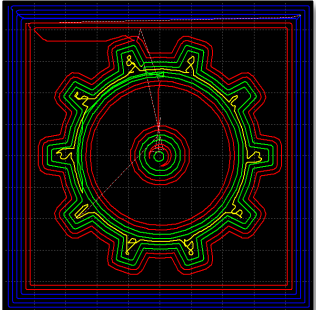


- GL-600
  - 3 powder print head
    - 0.12”, 1.0” nozzle ID
  - Gantry: 102”x24”x 24”
  - Capacity: 2000 lbs.





Multi-material CAD Model



3D Powder Print

- Bulk Processing**
- Furnace (Thermal)
    - Metals
    - Ceramics
    - Casting molds
  - CIP/HIP
    - Metals
  - Chemical
    - Casting Molds
  - Microwave (Thermal)
    - Ceramics
    - Metals



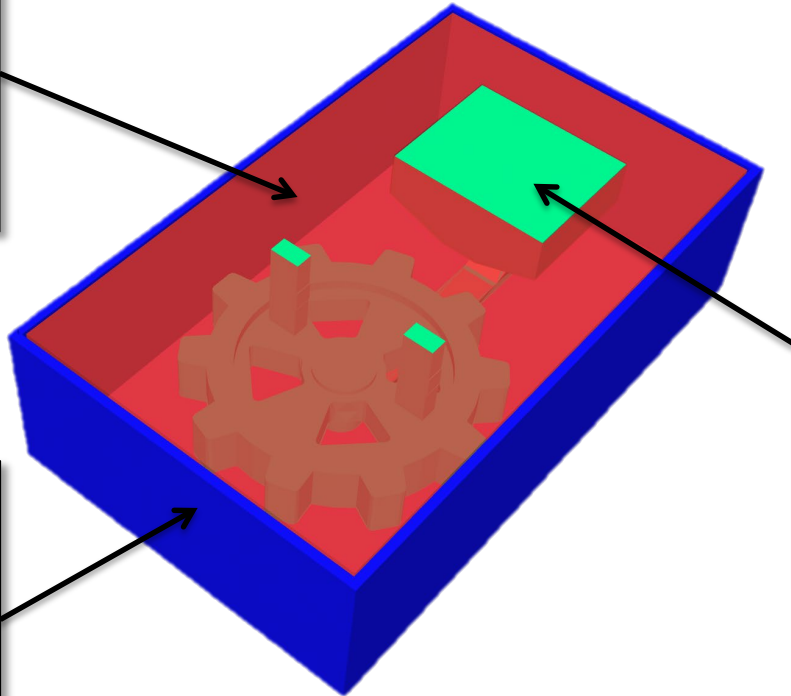


- Monolithic Casting Molds
  - No draft angles
  - No manual assembly of cope and drag
  - Rigging is part of the CAD model
  - OPL casting mold materials
    - Low cost
    - Non-toxic
    - Recyclable, reusable
- Metal Parts
  - Use commercial off-the-shelf powders
  - Efficient use of expensive powders
  - Infiltrated metal parts
    - 3D print porous metal preform and infiltrant metal
    - Single heat treatment
  - Sintered metal parts
    - Digital Powder Metallurgy





- **Mold Powder**
  - Forms the casting mold
  - Fuses during processing



- **Pattern Powder**
  - Forms the part and rigging
  - Maintains shape during processing
  - Is easily removed after the mold is set

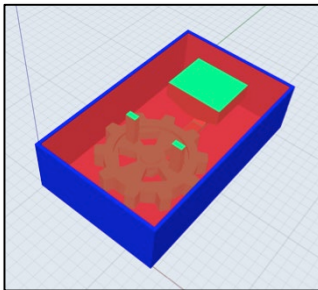
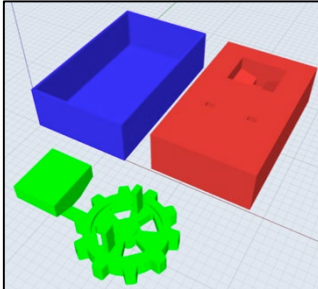
- **Support Powder**
  - Supports all other powders
  - Remains loose during processing



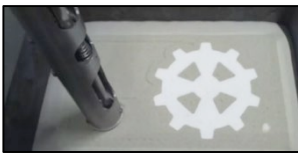
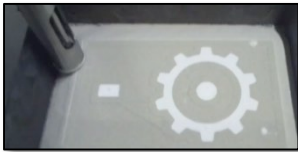


	Material	Cost (\$/kg)	Cost (\$/liter)	Hazardous	Reusable
<b>Pattern</b>	Salt Flour (NaCl)	~0.88	~0.91	No	No
<b>Support</b>	Zircon	~3.10	~8.37	No	Yes
<b>Mold</b>	Zircon/Sodium Silicate	~3.12	~8.42	Zircon: No Sodium Silicate: Slightly Basic	Yes: Water Wash (pH ~7)





Multi-material  
CAD Model



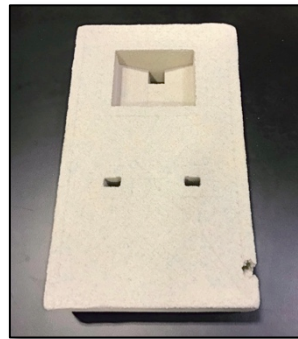
OPL Print



Heat Treatment  
750°C



Retrieve  
Mold/Pattern



Clear Pattern and  
Dry Mold



Cast Part



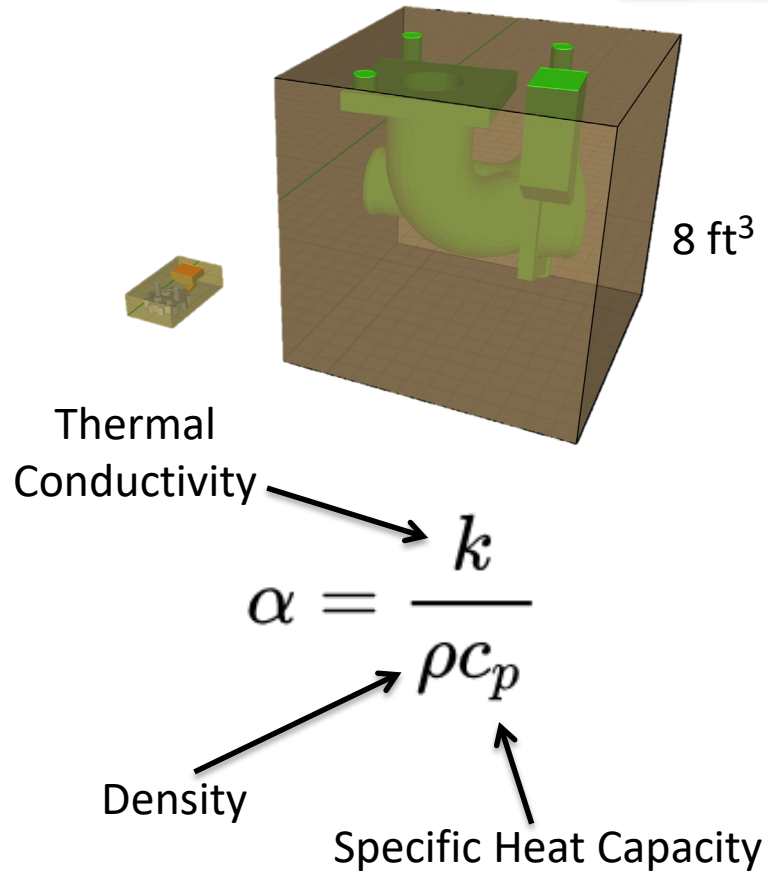
Part with Rigging





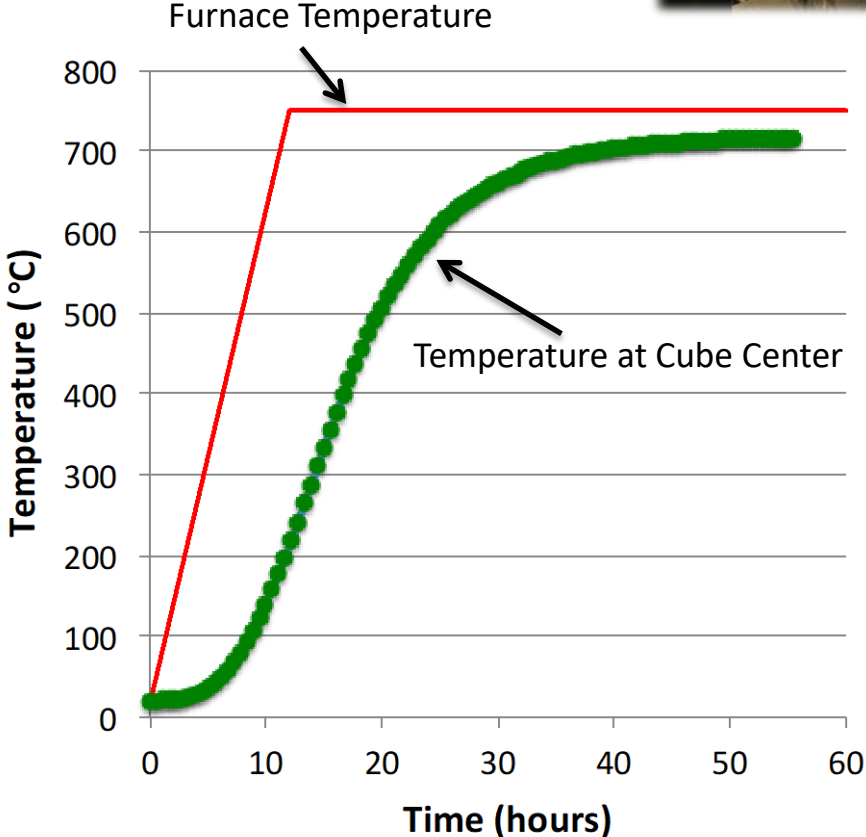
• Large-scale Casting Molds

- Zircon Bulk Density: ~2700kg/m<sup>3</sup>
- 2’x2’x2’ build: ~1400 lbs.
- The thermal mold set process is limited by the thermal diffusivity of zircon sand
- Thermal Diffusivities
  - Copper: ~111 mm<sup>2</sup>/sec
  - Steel: ~15 mm<sup>2</sup>/sec
  - Loose Dry Zircon: ~0.4 mm<sup>2</sup>/sec



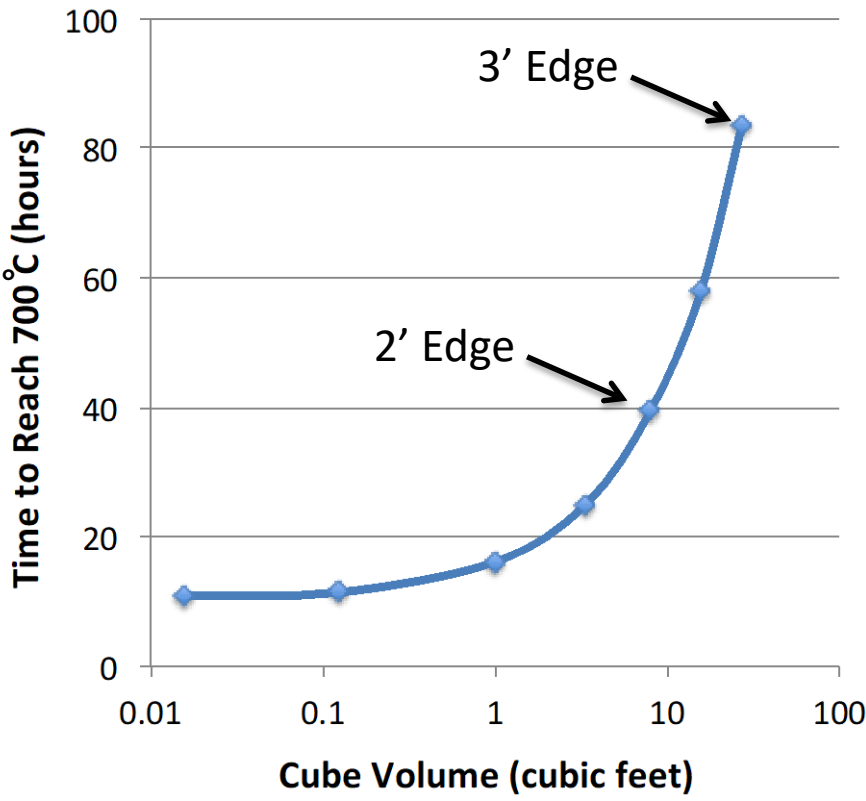


- Transient Thermal Analysis
  - Zircon Bulk Density: 2700kg/m<sup>3</sup>
  - Thermal Diffusivity: 0.4mm<sup>2</sup>/sec
  - 2'x2'x2' Cube (8 cubic feet)
  - Heating Schedule
    - 12 hour ramp to 750°C
    - Soak at 750°C





- Transient Thermal Analysis
  - Zircon Bulk Density: 2700kg/m<sup>3</sup>
  - Thermal Diffusivity: 0.4mm<sup>2</sup>/sec
  - Cube Models: 0.02 to 27 ft<sup>3</sup>
  - Heating Schedule
    - 12 hour ramp to 750°C
    - Soak at 750°C

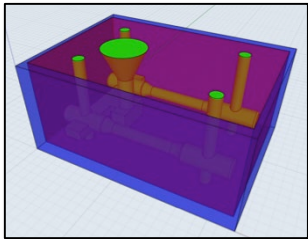
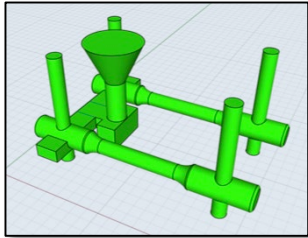




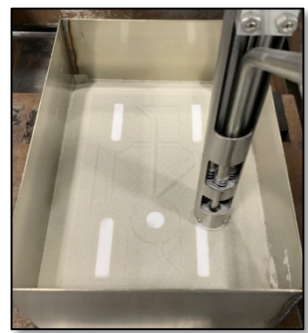
- Autoclave Processing
  - Dry steam can be used to chemically set the mold
  - OPL print is porous
    - Process is not limited by the thermal diffusivity of zircon sand
  - M-138 Field Sterilizer
    - 30 minutes at 135°C
    - Fast exhaust
    - 10 minute dry



M-138 Field Sterilizer



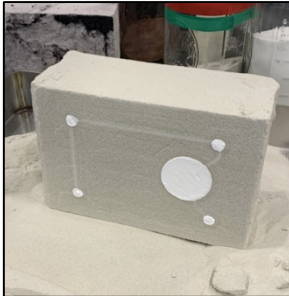
Multi-material  
CAD Model



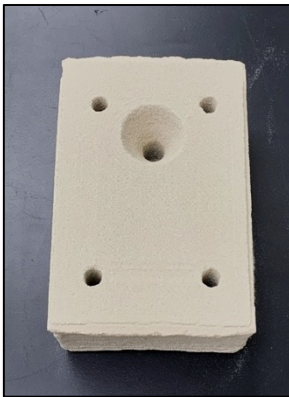
OPL Print



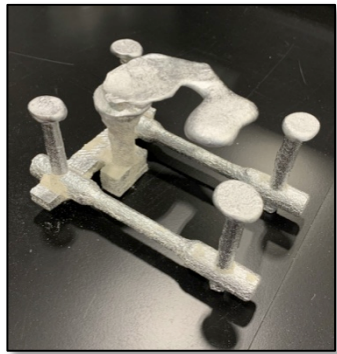
Heat Treatment  
135°C, 30 minutes



Retrieve  
Mold/Pattern



Clear Pattern and  
Dry Mold



Part with Rigging





- Monolithic Casting Molds

- Fast, dry steam mold set process
- Minimal handling of molds
- Reusable, low cost materials
- Dimensional Tolerance is similar to sand casting
  - Up to 6":  $\pm 0.030$ "
  - Each additional 1":  $\pm 0.003$ "



- Metal Parts

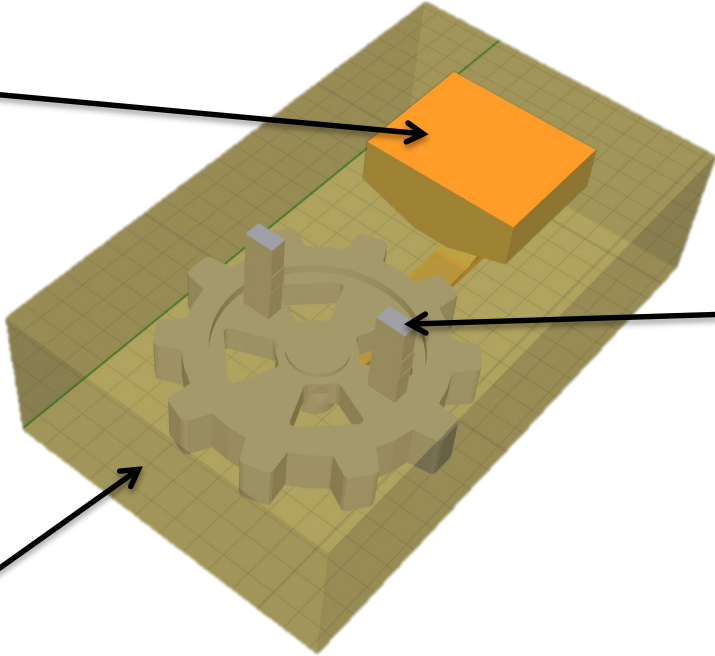
- Use commercial off-the-shelf powders
- Efficient use of expensive powders
- Infiltrated metal parts
  - 3D print porous metal preform and infiltrant metal
  - Single heat treatment
- Sintered metal parts
  - Digital Powder Metallurgy





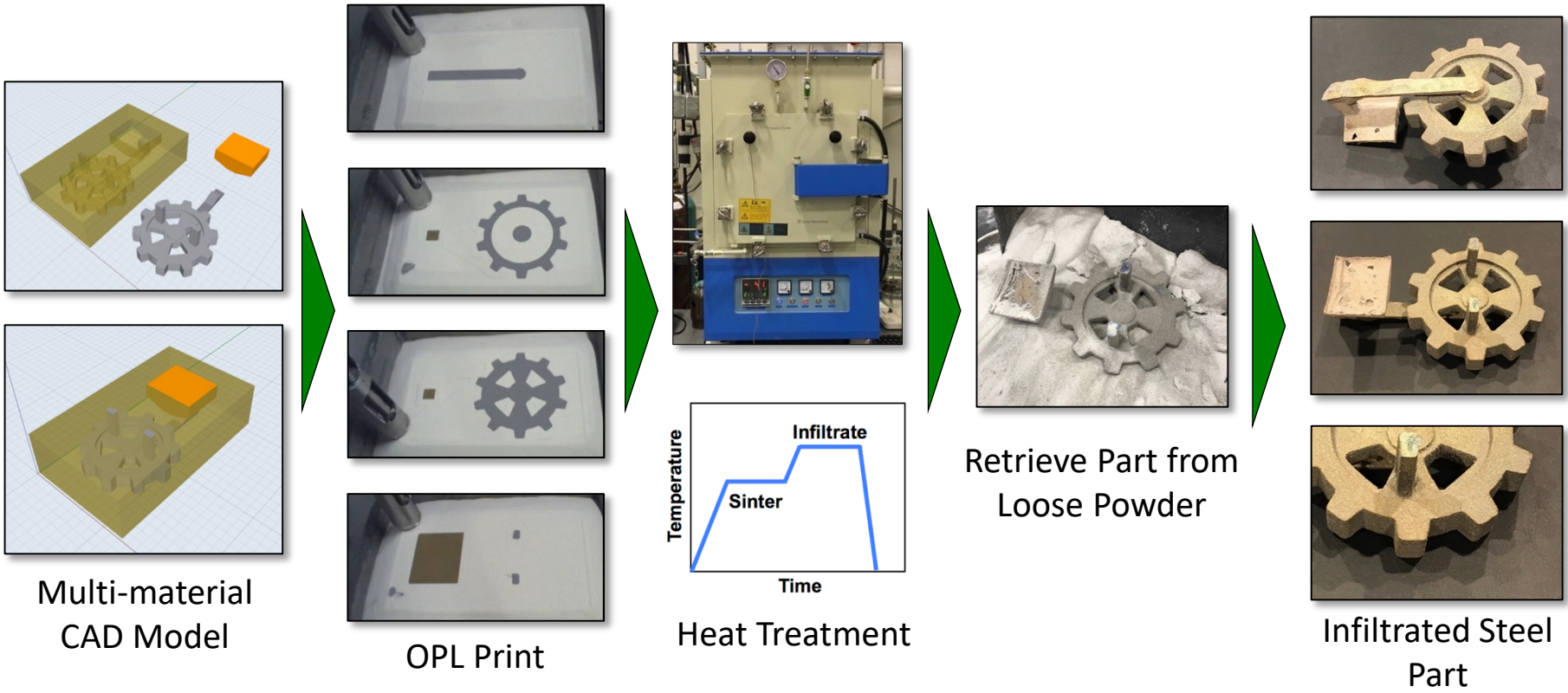
- Infiltrant Powder
  - Maintains shape during initial heat treatment
  - Infiltrates preform at high temperature

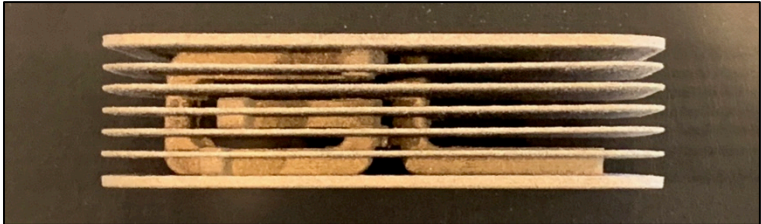
- Support Powder
  - Supports all other powders
  - Remains loose during processing



- Preform Powder
  - Forms the porous part skeleton
  - Maintains shape during processing
  - Is infiltrated with a metal alloy during heat treatment

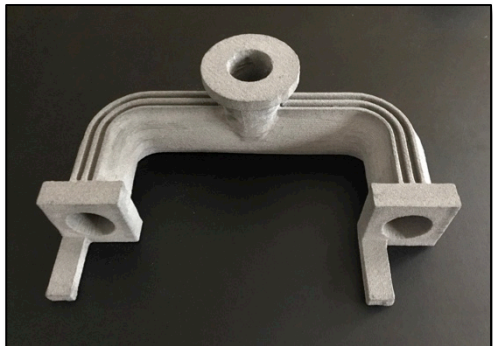




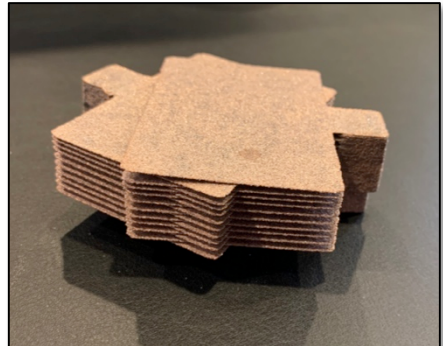


Copper Infiltrated Steel

UTS: 39,500 psi  
Yield: 19,100 psi  
Elongation: 9%



Copper Infiltrated Steel



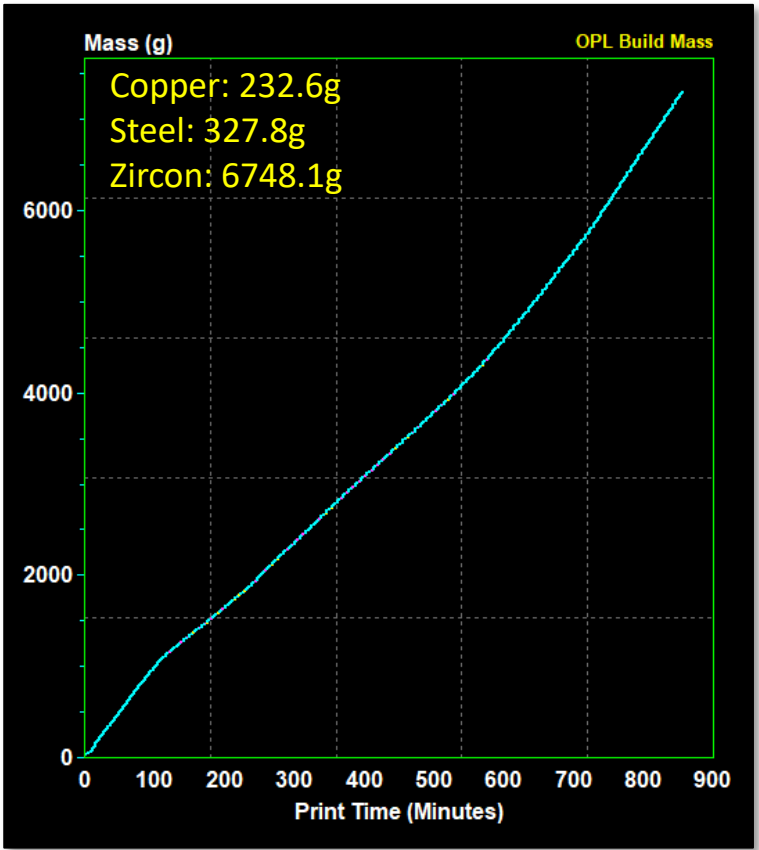
Ti-6Al-4V, V. Hammond ARL

Dimensional Tolerance: Up to 6": ±0.010"





- OPL Printing
  - Deposition rate
    - ~2 to 100cm<sup>3</sup>/min
  - XY feature Size
    - ~2 to 3mm
    - ~0.080” to 0.120”
  - Z feature Size: Powder Limited
- Repeatability
  - Pattern/Part/Infiltrant: <1%
  - Mold: <1%
  - Support: n/a

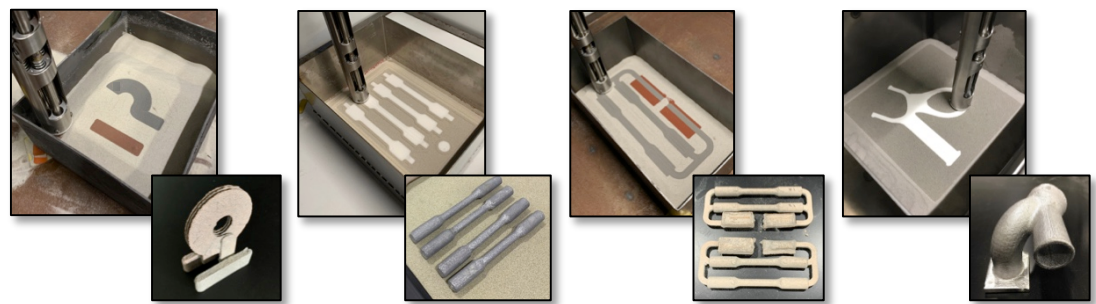




- Ordered Powder Lithography
  - Multi-material 3D printing of powders
  - Efficient use of expensive powder
  - Open-air operation
  - Binders not needed



- Bulk Processing
  - Monolithic casting mold fabrication
  - Metal part fabrication
    - Infiltrated Metals
    - Digital Powder Metallurgy





- OPL Development Team

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