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Indian Head EOD Technology Division

Metal Additive Manufacturing Structures for CAD/PAD Applications

2016 CAD/PAD Technical Exchange Workshop

NSWC IHEODTD

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Metal Additive Manufacturing

- Introduction
- Metal AM Process
- Positives and Negatives of Metal AM
- Obstacles to Implementation
- Designing for AM

Introduction

- ASTM F2792: “The process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.”
- This presentation will focus on one particular method of AM: metal powder bed fusion.
  - “Selective Laser Sintering”, “Selective Laser Melting”, “Direct Metal Laser Sintering”, etc
  - The use of concentrated heat (typically a laser) to fuse a bed of powdered material (in our case metal) into a solid structure
  - Most popular method of metal 3D printing

Powder Bed Fusion

Source: https://www.youtube.com/watch?v=I0l-GUEQus0

Example System

Laser-Based Powder Bed Fusion Metal AM

Source: NSWC IHEODTD

M2 LaserCUSING 3-D Metal Printer

Build envelope: 250 x 250 x 280 mm (x,y,z)
9.84“ x 9.84“ 11.02“

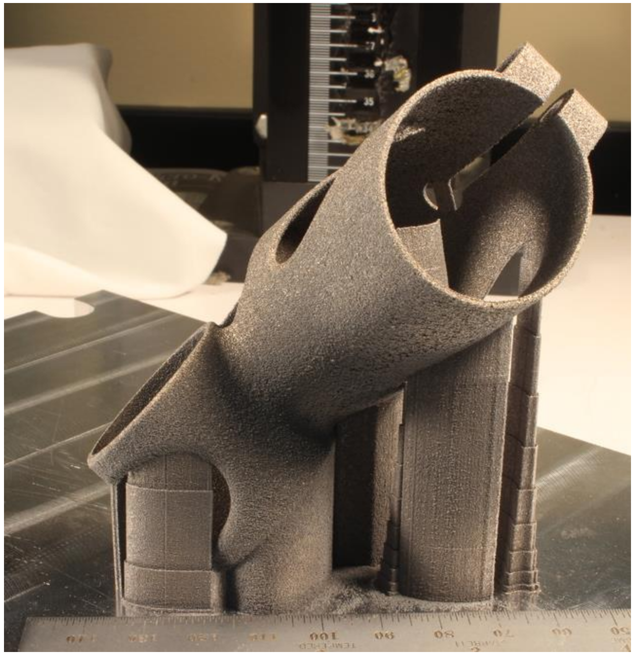
Laser System: 400 W

Materials:

1. High-grade steels
2. Stainless steels
3. Cobalt-Chrome alloys
4. Nickel-base alloys (Inconel)
5. Titanium alloys (Reactive)
6. Aluminum alloys (Reactive)

Fabrication Process

- Model and build preparation
  - Model converted to compatible format (typically STL)
  - Part is oriented and support structure added
  - Part is sliced and converted to machine format
- Fabrication
  - Build parameters determine laser path, intensity, deposition rate, etc
  - Oxygen is removed from build chamber and part is fabricated layer by layer
- Post-processing
  - Part is excavated from powder
  - Build plate is removed via band-saw or wire EDM
  - Secondary operations finish part



Source: Google Image Search

What are the benefits?

- Create net and near-net shape parts out of metal
  - Parts created directly from 3D models
  - Solid steel parts (fully dense, no porosity)
  - Parts can be welded, machined, etc
- High level of precision
  - Tolerances dependent on melt pool size (~0.005”)
- Unique geometries
  - Complex shapes
  - Internal structures
- Rapid turnaround
  - Build time based on volume and height
  - Complexity has minimum impact
- Flexibility
  - Designs can be rapidly changed

Source: Google Image Search

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What are the downsides?

- One material (monolithic structure)
- Slow build process
  - Dependent on part volume and height
  - Typical machine can process 2-20 cm^3 per hour depending on material
  - Example: Four 60mm cylinders approximately 200mm tall with ~4kg/500 cm^3 volume maraging tool steel required five days to build
  - Order of magnitude faster processing times with production grade machines
- Post-processing
  - Parts are effectively welded to the build plate
  - Surface finish dependent on orientation and powder
- Verification and Validation
  - Proprietary materials and parameters
  - Relationship between characteristics and build parameters still not fully understood
- Specialized design requirements

Designing for Metal AM

- No unsupported overhangs or islands
  - Minimum ~45 degree angle without support
  - Layered construction requires all of the part to be connected to the build plate at all times
  - Circular holes parallel to build plate will need to be drilled out
  - Undercuts will feature very poor surface quality
- Trapped powder
  - Need to accommodate powder removal during design and fabrication
  - Enclosed voids will have powder trapped in them
- Thermal stresses
  - Welding a bed of powder creates massive thermal stresses
  - Part warping can occur, may result in lost build
  - Heat treating may be required
  - Ideal build has similar cross-section between layers
- Post-processing
  - Must accommodate support removal and fixturing of part

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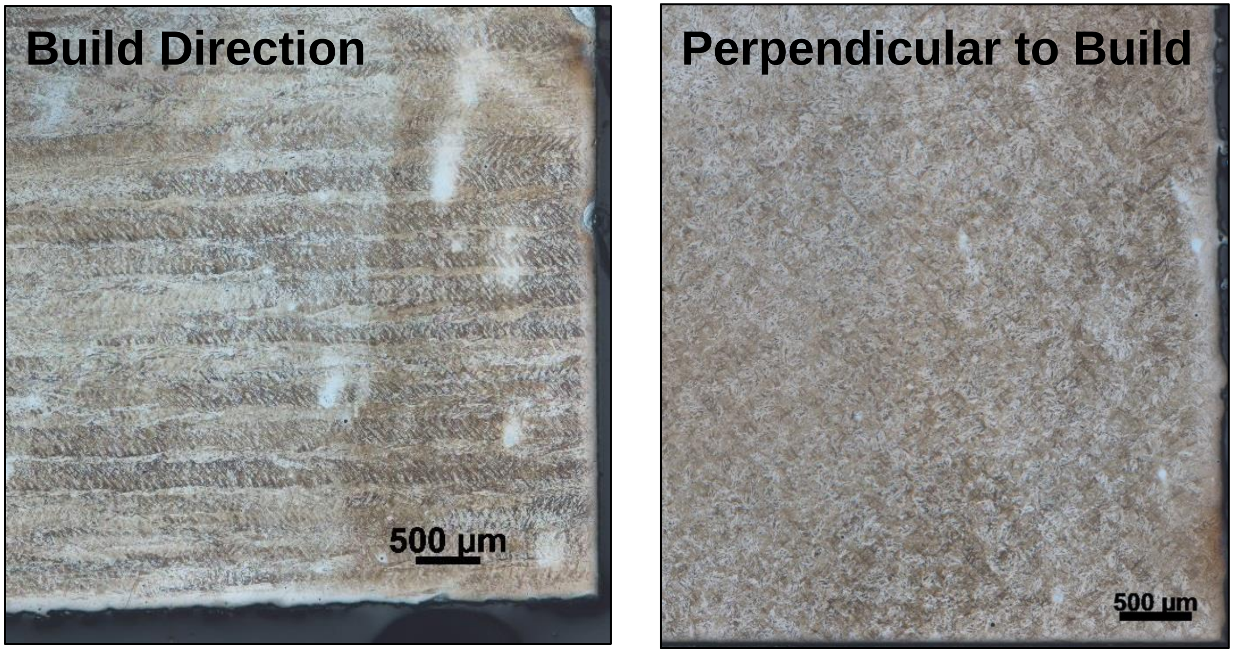
Challenges to Implementation

- AM is extremely process specific
  - Machine
  - Build process parameters (hundreds of variables)
  - Part orientation
  - Number of parts on plate
  - Powder properties
- This requires a new way of thinking with respect to the technical data package (TDP)
  - Process closer to welding than machining
  - Understanding interplay between variables is crucial to deciding what must be controlled
  - End result could be TDPs hundreds of pages long
- Qualification, Certification, and Inspection
  - Ensuring that what’s built in a decade still meets design intent
  - Determining criticality of parts to establish level of rigor
  - Developing inspection processes for intricate metal geometries

Example: Build Orientation



NSWC IHEODTD AM Tool Steel Micrographs

- Grain structure changes depending on build orientation
- Result is anisotropic material properties
- TDPs may need to specify orientation and process parameters

Energetic Specific Challenges

- Lack of information on AM material properties
  - Dynamic response
  - Material models for simulation
- Limited material availability
  - Alloys
  - Reactive materials
- Lack of experience explosively loading AM structures
  - Material compatibility
  - Geometry
- Lack of energetics which match the flexibility of AM
  - Low viscosity materials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