Additive Manufacturing Technology and Trends

*MCA Session Topic: Generalizing Fundamental AM Principles*

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Instructors:
1. Alex Raymond Renner: arenner@iastate.edu
2. Spencer Rea: sprea27@iastate.edu
Machine Movement Overview

- Machine component movements and material bonding methods must work together
- A machine with specific movements can use different materials
- Material properties are part of designing an AM machine
  - This makes AM fundamentally different than any other manufacturing technology
  - The machine component movement capabilities are always better than the tolerances of the produced part
  - Analogous to designing a Quality Assurance device
- Non-linear relationship between machine movement accuracy and final part accuracy
## Simple Definitions for “Complex” AM Systems

<table>
<thead>
<tr>
<th>Machine Movements</th>
<th>Materials &amp; Bonding Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active vs. Passive</td>
<td>Plastic Filament, Heat &amp; Pressure</td>
</tr>
<tr>
<td>Motors &amp; Gears</td>
<td>Glue &amp; powder</td>
</tr>
<tr>
<td>Motors &amp; Jets</td>
<td>Resin &amp; UV</td>
</tr>
<tr>
<td>Mirrors &amp; Motors &amp; Masks</td>
<td>Resin &amp; Lasers</td>
</tr>
<tr>
<td>Mirrors &amp; Lasers &amp; Lenses</td>
<td>Special Powders &amp; Lasers</td>
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</tbody>
</table>
Platform Movements

- Passive systems:
  - Support Material moves with part
    - StereoLithography
    - 3D printed (glued powder, Zcorp)
    - Thermo and Multi-Jet Printing
    - Sintering
  - Purpose/Use-case priority
    - Aesthetics / Display
    - Feel
    - Function

- Active systems:
  - Support (if needed) created simultaneously with part
    - Deposition:
      - FFF, FDM, MEMS
      - 3D printed (glued powder, Zcorp)
      - Thermo and Multi-Jet Printing
      - Melting
      - SLM, LENS, EBM
  - Purpose/Use-case priority
    - Function
    - Feel
    - Aesthetics / Display
AM Processes

FDM

SLA

SLS

DMLS

Polyjet

Passive Supports
Post-Processing

IOWA STATE UNIVERSITY
VRAC  View, Analyze, Process, Collaborate
# AM Machine Specifications

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Tolerance Range (in.)</th>
<th>Materials</th>
<th>Material &amp; Part Properties</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFF</td>
<td>0.0000X -&gt; 0.0X</td>
<td>Thermoplastic filament</td>
<td>Varies based on user</td>
<td>Function of Cost</td>
</tr>
<tr>
<td>FDM</td>
<td>0.001 -&gt; 0.010</td>
<td>ABS filament</td>
<td>&gt; 60% of other mfg. processes</td>
<td>Fit, and some function</td>
</tr>
<tr>
<td>Fused Powder</td>
<td>0.0001 -&gt; 0.005</td>
<td>Thermoplastic &amp; thermoset powders</td>
<td>Poor, requires post-processing</td>
<td>Fit, Form, Function, Communication</td>
</tr>
<tr>
<td>SLA</td>
<td>0.0001 -&gt; 0.003</td>
<td>UV cured polymers</td>
<td>Fair</td>
<td>3D shape and</td>
</tr>
<tr>
<td>Polyjet</td>
<td>0.00005 -&gt; 0.0005</td>
<td>UV cured polymers, plastics, rubber</td>
<td>Good</td>
<td>Small features, multi-material prototypes</td>
</tr>
<tr>
<td>SLS</td>
<td>0.0001 -&gt; 0.001</td>
<td>Ceramics, Thermoplastics</td>
<td>Good</td>
<td>Wide variety, based on material</td>
</tr>
<tr>
<td>DMLS</td>
<td>0.0001 -&gt; 0.001</td>
<td>Ceramics, Metals</td>
<td>Very Good, semi-porous</td>
<td>Industrial use, complex internal geometric features</td>
</tr>
<tr>
<td>SLM, LENS, EBM</td>
<td>&gt; 0.0001</td>
<td>Metals</td>
<td>Fully Dense</td>
<td>When it can't be made or repaired in any other way</td>
</tr>
</tbody>
</table>
PolyJet

- Stratasys trade name for multi-jet technology for UV cured photopolymers
- Cannot be used with Thermoplastics which require FDM/FFF processes
Selective Laser Sintering

- Sintering is not melting
  - Laser power dependent on material, 25-100W laser is typical
  - Chamber is heated to below melt temperature of material
  - Nitrogen used to avoid oxidation and/or explosion

- Process Steps:
  - Laser beam directed through use of galvanometric mirrors
  - Un-fused powder serves as passive support structure
  - Supply platform raises and build platform lowers
  - Counter-rotating roller sweeps powder layer from supply
  - One layer thickness of powder ready for sintering
  - Laser sinters a layer
  - Platform moves down after sintering
  - Fresh new powder layer (slow step, compared to laser sintering step)
  - Build Platform raises out of the build chamber
Direct Metal Laser Sintering (DMLS)

- Higher power lasers and chamber temperatures allow direct sintering of metal powders or selective melting
- Lasers 200W +
- Slower scan speed (~118 ips) versus 300-400 ips for SLS
- Layer thickness (~0.001”-0.004”)
DMLS: Materials and Processing

- Polyamide (Nylon)
- Glass filled Polyamide
- Polycarbonate
- Elastomeric materials (rubber like)
- Zircon (ZrSiO4) and Silica (SiO2) sand (coated)
- Metal powders (coated)
Melting: Selective Laser (SLM), Electron Beam (EBM)

- EBM uses electron beam for power and must have conductive materials (lasers can heat others)
- Surface finish in all processes can be a challenge
- Shrinkage and distortion of parts can be a problem
- SLM and EBM can make fully dense parts in metal
- All machines are relatively expensive, EBM and SLM being the most
- Relatively small build envelopes for metal parts
Hybrid

- Support (if needed) created simultaneously with part
- Deposition:
  - Laser Engineered Net Shape (LENS)
  - Thermo and Multi-Jet Printing
  - Shape Deposition Manufacturing (SDM)
- Purpose/Use-case priority
  - Function
  - Feel
  - Aesthetics / Display
Thermojet / Multi Jet

- Very high accuracy and good surface finish
- Niche application in jewelry making and dental/medical
- Great for investment casting small parts
- Deposits molten material which solidifies on contact
- Low viscosity molten thermoplastic
- Active support structures using different material
- Low melt temperature, low viscosity
- Intended for investment casting
- Support Material: Natural and Synthetic waxes and Fatty Esters
- Melt temp 120°F-158°F
Shape Deposition Manufacturing (SDM)

- A hybrid method using both additive and subtractive manufacturing

- Decompose complex shape into layers (arbitrary depth) such that the part can be made with simple operations

- Either machine a cavity and deposit material, or deposit material and machine the shape
Laser Engineered Net Shape (LENS)

- Uses a focused laser to melt powder and build layers
- Powder is supplied via nozzles around the laser
- Laser, typically Neodymium Yttrium Aluminum Garnet (Nd:YAG) focused with a lens to the build location
- Several nozzles supply metal powders to focal point of laser
- Creates fully dense metal parts and tooling
- Laser power: 500W to 20kW

Materials
- Titanium
- Stainless Steel – Inconel

- Can process reactive materials because of inert environment
- LENS process is good for depositing expensive and/or difficult to machine metals
It is expected that LENS parts/tooling will be machined

Extra material purposely deposited for this reason

Substrate may need to be removed

Post processing alone could exclude LENS from “rapid” category...

Large use of the LENS process is repair of existing parts

Cracked/Broken parts filled with metal in selective regions using LENS process

Saves costly replacements

Repair is as strong or stronger than original material
Post Processing, Maintenance, & Quality Assurance

- “I’m melting”: water soluble supports
- “I’m not melting but I am feeling a bit hygroscopic”: help control the wet filament population, have your filament stored and adsorbed
- “I think I’m melting”: FDM vs. FFF (why your extruder is probably clogged)
- “I wish I was melting”: you can’t “print metal” but you can sinter it
- “I overcooked it”: laser power and angle of incidence in a heated build chamber
- “I wasn’t roughhousing”: post-processing steps non-AM quality assurance inspection standards applied to AM parts
- “I’m not done with it, but it printed”: the often forgotten but beneficial post-processing steps
- “I’m for sure melting”: how to make fully dense metal parts using AM processes/techniques
Post Processing: Sintering

- Parts must be extracted from contents of the build chamber, parts must be found in a “block” of material and cleaned.

- Cost increases with part complexity and quantity of parts (very little material can be recycled).

- “The Shapeways Factory is a Modern Santa Klaus’ FabLab”
That’s not a multi-tool! This is a multi-tool

- Extruder for ceramics
- Extruder Bowden
- Head for cartridges
- FDM head 1.75mm
- Head for drawing
- FDM head 3mm
- Head for milling
- Cutting head
- Carvers head
- Laser head
Emerging AM Methods

- Self-Propagating Photopolymer Waveguides (SPPW)
  - Lattice-based open-cellular materials
  - Shorter manufacturing time vs. SLA

- Layer-Less AM processes
  - Could be applied to multiple AM system types
  - Borrows concepts from CNC machining
Emerging AM Methods

- In-situ FFF painting
- CMYKW FDM