Additive Manufacturing Technology and Trends

MCA Session Topic: Generalizing Fundamental AM Principles

7/1/22

Alex Raymond Renner
arenner@iastate.edu
AM Machines

LeBigRep (FFF)
MakerBot 2X (FFF)
Delta RepRap (FFF)
KickStarter Tiko (Delta FFF), $180

Zcorp 3D Printer
Stratasys (FDM)
Stratasys (PolyJet)
EOS (SLS)
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>
</tr>
</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

Polyjet

Passive Supports

Post-Processing
## 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>

Virtual Reality Applications Center
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”)

Virtual Reality Applications Center
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
Laser Engineered Net Shape (LENS) cont...

- 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
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