Three Dimensional Printing

Emanuel Sachs
Professor of Mechanical Engineering
sachs@mit.edu
Three Dimensional Printing

Sachs, Emanuel

MIT

Office of Naval Research

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See Also ADM001348, Thermal Materials Workshop 2001, held in Cambridge, UK on May 30-June 1, 2001. Additional papers can be downloaded from: http://www-mech.eng.cam.ac.uk/onr/

3D Printing is an SFF Process which creates parts in layers. Each layer is formed by spreading powder and selectively joining the powder by ink-jet printing of a binder material.

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19. NAME OF RESPONSIBLE PERSON
Fenster, Lynn
fenster@dtic.mil

19b. TELEPHONE NUMBER
International Area Code
Area Code Telephone Number
703767-9007
DSN
427-9007

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# 3DP™ Team

<table>
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<tr>
<th>FACULTY</th>
<th>RESEARCH STAFF</th>
<th>GRADUATE STUDENTS</th>
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<tr>
<td>Emanuel Sachs</td>
<td>James Serdy</td>
<td>David Ables</td>
</tr>
<tr>
<td>Michael Cima</td>
<td>Chris Stratton</td>
<td>René Apitz</td>
</tr>
<tr>
<td>Samuel Allen</td>
<td>Benjamin Polito</td>
<td>Diana Buttz</td>
</tr>
<tr>
<td>Nick Patrikalakis</td>
<td></td>
<td>David Guo</td>
</tr>
<tr>
<td>Linda Griffith</td>
<td>Post-Docs and Visitors</td>
<td>Richard Holman</td>
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The 3D Printing Process

3D Printing is an SFF Process which creates parts in layers. Each layer is formed by spreading powder and selectively joining the powder by ink-jet printing of a binder material.

- Any material as a powder
- Scaleable with multiple nozzles
- Local Composition Control
MIT’s 8-jet Printhead

Allows for wide range of materials, precise droplet location and scalability.

Printing a layer
Removing the Green Part from the Powder Bed
Office Modeler;
Z Corp., Burlington, MA

- Low cost machine.
- Office environment (water binder, starch powder or plaster based)
- High reliability.
- FAST
Ceramic Molds for Metal Castings;
Soligen, Inc. Northridge, CA

- 3D Print Ceramic mold
  - Colloidal silica binder into alumina powder
- Fastest route to a casting.
- Soligen Operates “Parts Now” which accepts files and returns castings.
Filters;
Specific Surfaces,  Franklin, MA

- **Focus:** ceramic filters for power plants - high filter area, durable, cleanable.
- **Successful tests in “bag houses”** (2000 hours). Tests on full scale pilot plant next. EPRI funded.
Medical Applications;
Therics, Inc. Princeton, NJ

- Drug delivery devices.
- Scaffolds for tissue engineering.
- Direct printing of tissue and organs.
- Direct printing of metallic prostheses.
Direct Printing of Metal Tooling;
ExtrudeHone Corp., Irwin, PA

- Directly print metal tooling.
  - Polymer binder into metal powder.
Tooling by Direct Printing

- Colloidal latex binder
- Stainless steel or tool steel powder

Remove unprinted powder

Green part
58% metal
10% polymer
32% open porosity

Debind by thermal decomposition & pre-sinter to 63% dense

Infiltrate to full density with copper alloy

Finish
Tool Insert
Finished Tool and Molded Part
Conformal Cooling in an Industrial Application

Tool made by 3D Printing with serpentine cooling channel

<table>
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<tr>
<th>Condition</th>
<th>Improvement over Production Tool</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Cycle time</td>
</tr>
<tr>
<td>Condition #1</td>
<td>15%(limited by sprue)</td>
</tr>
<tr>
<td>Condition #2</td>
<td>0%(limited by sprue)</td>
</tr>
</tbody>
</table>
Conformal Cooling; Data from Design of Expt’s

- Typically
  - 20% reduction in cycle time
  - 15% reduction in shrinkage

Schmidt et al, “Conformal Cooling vs Conventional Cooling: An Injection Molding Case Study with p-20 and 3DP tooling, MRS 4/00
Partnership in Technology

- Blow Mold Cavities
  - MoldFusion™ First Design
    - Two conformal and opposing flow circuits
  - MoldFusion™ Second Design
    - Two conformal linear flow circuits
    - Turbulence chevron features
Demonstration of Performance: Conformal Cooling

![Graph showing temperature change over time](image)

- Time (sec)
- Temperature (°C)
Conformal Cooling Condition

\[
\frac{L^2}{k} < \frac{\text{Cycle Time}}{\rho c}
\]
Conformal Cooling Channel Design Methodology

- Design for conformal cooling
- Design for sufficient cooling
- Design for temperature drop
- Design for cooling uniformity
- Design for pressure drop
- Design for mold strength & deflection

Map to entire mold

before design

after design

Map to entire mold
Surface Textures for Heat Transfer Augmentation

[Diagram showing a block with labels for Thermocouple Holes and Flexible Heaters]
Pressure Drop ($\Delta P$)

$\Delta P$ (psi)

Reynolds Number

- Chevron
- No ribs
Rapid Thermal Cycle Tooling

Mold Temperature

Time

Inject Part

Eject Part

Constant Temperature

Cycled Temperature
3D Printed Tool for Rapid Thermal Cycling

The tool has cooling/heating channels in the top plate and stands on 2000 posts (which allow for thermal expansion/contraction)
Homogeneous Metal Parts by Infiltration

Porous skeleton of nickel or other high temperature material

Infiltration using same material containing a melting point depressant (MPD)

Diffusion of MPD into skeleton creates a solid homogeneous part

~1 min ~1 hour

Porous skeleton → Infiltration → Diffusion → Solid Part

~1 kg infiltrated part (Ni–4Si)
Infiltration Distance

- Capillary limit
  \[ h = \frac{1}{2\gamma} \cdot \frac{\rho g}{r} \]
  >0.5 m typical for 100 μm powder

- Premature freezing of infiltrant can choke liquid flow

Skeleton made of ~ 50–150 μm powder (both cases)

Ni infiltrated with Ni-10Si
Steel infiltrated with Cu
Solidification Time Sequence

- Wire bundle infiltrated and quenched at various times
- Ni wire w/ Ni–10Si infiltrant
- Infiltrated at 1200°C
Solidification Time Sequence

- Wire bundle infiltrated and quenched at various times
- Ni wire w/ Ni–10Si infiltrant
- Infiltrated at 1200°C
Mechanical Properties

- Infiltrated skeleton held 12 hrs at 1200°C for homogenization
- Cast ingot of same composition
- Hopefully Cr or other elements will provide more strengthening

Tensile Tests of Ni-4Si Specimens

- Infiltrated Skeleton
- Cast Ingot
- Inf before heat treat
- Inf before heat treat
Other Material Systems

- **Al–Si**
  - Low solubility (no freeze-off)
  - Similar to cast microstructure
  - Pure Al infiltrated w/ Al–12Si at 625°C achieved 93.5% density

- **Ni–Cr–Si**
  - solid solution strengthening
  - keep constant Ni:Cr ratio during diffusional solidification

- **Steel?**
3D Printing: Dry vs. Wet Layer Spreading

Dry
- Spherical as small as 10 μ
- Acicular as small as 20 μ

Wet
- Anything that can be slurry processed
Parts with Fine Metal Powder
Architecture 1: Stationary Bed, Raster Print

- Gantry
- Fast Axis
- Slow Axis
- Feed Piston
- Powder Spreading Roller
- Printhead Inspection

Z Corp.
ExtrudeHone Corp.
Small Parts; Distinguishing Features

- Powder beds are small, light (<1 kg) and often cohesive.
  - Move powder bed
- Perimeter is short
  - Vector Print the perimeter.
1. Substrate Load & Unload
2. Layer Forming
2a. Layer Inspection (Done in transit)
3. Layer Drying
4. Binder Printing
5. Binder Drying

Architecture 2: Moving Bed, Vector Print

- All stations in use all the time.
- Automation ready.
- Improved surface finish.
Barrium Titanate Parts made by 3DP with Slurry
Local Composition Control; Like Color ink-jet Printing, but with Materials

Titanium Carbide slurry printed in Moly powder; 83% dense
Summary:
3DP for Thermal Management

• Cooling/heating channels - high complexity
• Surface textures
• Macro cellular structures
• Locally controlled porosity
• Locally controlled thermal conductivity