Manufacturing and Security Challenges in Additive Manufacturing

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Why additive manufacturing

- Nickel-alloy turbine rotor produced by SLM
- Hydraulic crossing made from 1.4542/17-4 PH stainless steel
- Complex internal features cannot be produced by other methods

Image courtesy: Dr. Dirk Lehmhus, Fraunhofer IFAM, Bremen, Germany
Additive manufacturing methods

Fused Deposition Modeling

- A filament is heated in the extrusion head and extruded from the nozzle
- The extrusion head moves according to the generated 2D toolpath of each layer
- The 3D model is built layer by layer
- Support material is built for hollow or overhanging structures, and can be easily removed from the model
- Most commonly used FDM filament materials are ABS and PLA
- Relatively cheaper but less accurate
FDM 3D printers and products

Stratasys Dimension Elite

Stratasys Connex500

Flashforge Creator Pro Dual Extrusion

Dual extrusion FDM

Complex geometry by FDM
Additive manufacturing methods

Selective Laser Sintering

- A layer of powder is spread uniformly on the building platform
- A laser power source is used to selectively melt/sinter the powder particles based on the 2D toolpaths
- The powder particles are heated to/close to melting points and then solidify to form the 3D object layer by layer
- Powders can be metal, polymer or ceramics
- More expensive but can produce industrial level products
SLS 3D printers and products

EOSINT M 280 DMLS (Direct Metal Laser Sintering) system

EOSINT FORMIGA P110 (AM for polymer parts)

As built SLS Aluminum

Polished SLS Aluminum
Additive manufacturing chain

Security concerns in digital chain

Sony Pictures Entertainment hacked

Elizabeth Weise, USATODAY
8:16 p.m. EST November 24, 2014

SAN FRANCISCO - Sony Pictures Entertainment was hit by hackers on Monday and the company told employees to turn off their computers and disable Wi-Fi as a result, reports say.

Visa Database Found to be Vulnerable to Hacking: Report

by REUTERS

Cyber security experts have found vulnerabilities in a State Department system that could have allowed hackers to alter visa applications or steal data from the more than half billion records on file.

ABC News first reported on the issue, citing sources familiar with the matter.

Volkswagen, Israeli group form car cybersecurity firm

Elizabeth Weise, USATODAY
5:47 p.m. EDT September 10, 2016

SAN FRANCISCO - When cars can talk to the Internet, hackers can talk to cars. Which is why Volkswagen has become the latest in a string of companies entering the automotive cybersecurity realm.

The German company is collaborating with three former employees Israel’s Shin Bet intelligence agency, including Yoval Daskin, the agency’s former head, to found SyMotive Technologies.
Additive manufacturing chain

Problem statement

• Network security is the only line of defense in most cases
• Once is it breached, the IP and data are immediately at risk
• A counterfeit part is as good as the original part

• Security features through
  • Innovative CAD strategies
  • Traceable markers inside parts
  • Cybersecurity tools and methods

• Self-diagnosis capability in each step
• Self-certification capability against tempering
• Identify critical vulnerabilities
Curvature effects

STL file resolution affects part appearance

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Coarse</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation (cm)</td>
<td>$1.215 \times 10^{-2}$</td>
<td>$4.681 \times 10^{-3}$</td>
</tr>
<tr>
<td>Angle (°)</td>
<td>30.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>
Polymer (ABS) samples printed in different orientation by FDM

<table>
<thead>
<tr>
<th>FDM specimen</th>
<th>Ultimate strength (MPa)</th>
<th>Modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/90° cross</td>
<td>21±3.3</td>
<td>2058±31.1</td>
</tr>
<tr>
<td>±45° cross</td>
<td>18±0.3</td>
<td>2004±74.3</td>
</tr>
<tr>
<td>Z</td>
<td>10±1.2</td>
<td>1535±96.5</td>
</tr>
</tbody>
</table>
AlSi10Mg specimen as fabricated versus polished

- Top surface roughness is due to cutting off from the build plate
- The bottom surface roughness is due to SLM process
- The specimen thickness is reduced by about 1 mm after polishing
Porosity distribution from Micro CT-scan

<table>
<thead>
<tr>
<th>CT scan parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Source voltage (kV)</td>
<td>80</td>
</tr>
<tr>
<td>Source current (µA)</td>
<td>124</td>
</tr>
<tr>
<td>Source-object distance (mm)</td>
<td>56.951</td>
</tr>
<tr>
<td>Object-detector distance (mm)</td>
<td>214.924</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CT Analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent object volume</td>
<td>96.96%</td>
</tr>
<tr>
<td>Total porosity</td>
<td>3.04%</td>
</tr>
</tbody>
</table>

Reconstructed CT scan images of the cylindrical as-printed aluminum specimen showing porosity distribution

- Development of methods to remove the porosity – HIP?
- Development of heat treatment methods

*Image pixel size: 2.38µm*
Microstructure of AlSi10Mg specimen as fabricated

- Heat treatment
  - 550 °C in furnace for 10 hours
  - Cooled down in furnace to 200 °C
  - Cooled down to room temperature
Destructive test

Top surface of the SLS AlSi10Mg tensile bars

Bottom surface of the SLS AlSi10Mg tensile bars, due to removal from the build platform

<table>
<thead>
<tr>
<th>SLS specimens</th>
<th>Ultimate strength (MPa)</th>
<th>Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°</td>
<td>324.0 ± 18.0</td>
<td>61 ± 1.0</td>
</tr>
<tr>
<td>0°</td>
<td>285.0 ± 10.2</td>
<td>69.0 ± 2.8</td>
</tr>
</tbody>
</table>
Summary

- Rapid growth of 3D printing is expected to continue in the next five years
- The technique is relatively well developed for pure polymers and metals
- Expansion of the technique to other materials, including composite materials
- Securing the 3D printing supply chain is a major challenge
- Malicious activity can be from inside or outside of the supply chain
- Cybersecurity tools can be deployed but CAD design with embedded security features can be very useful