Additively Manufactured Lattice Structure Thermal Characterization

Travis Belcher, NASA MSFC

Presented By
Travis Belcher
Agenda

• Lattice Structure Introduction
• Thermal Analysis
• Current Experiments
• Proposed Experiments
Lattice Structures

ECLSS 4-Bed Molecular Sieve (4BMS-X) Heater Plate
Lattice Structures

- Lattice Structures are repeating patterns which can be applied to Additively Manufactured (AM) parts
- Four lattice topologies were selected for assessment (1)
  - Dode Medium – 13% Relative Density (%RD)
  - Diamond – 20%RD
  - Octet Truss – 30%RD
  - Rhombic Dodecahedron – 20%RD
- Two unit cell sizes were down-selected
  - Coarse: 5mm
  - Fine: 2mm
Lattice Structures

Advantages
• Reduced mass, retain stiffness
• Variable relative density and surface area
• Tailorable thermal conductivity ($k$) to specific applications

Limitations
• Computationally expensive for analytical modeling
• Limited material property data (traditional properties are unreliable)
Early Modeling Attempts

- **Steady State**
- **Dimensions**
  - Width: 20mm
  - Length: 20mm
  - Thickness: 0.98mm
- **Assumed Constant Aluminum Properties**
  - \( k = 205 \text{ W/m-K} \)
  - \( C_p = 0.9 \text{ J/g-K} \)
  - \( \rho = 2700 \text{ kg/m}^3 \)
Lattice Structures $k$ Analysis

Effective Thermal Conductivity ($k_{eff}$)

$$k_{eff} = \frac{QL}{A\Delta T}$$

- $Q$ - Heat Flux
- $A$ - Cross-Sectional Area
- $L$ - Length
- $\Delta T$ - Differential Temperature

Thermal Diffusivity ($\alpha$)

$$\alpha = \frac{k_{eff}}{\rho_{eff}C_p}$$

- $C_p$ - Specific Heat Capacity

Effective Density ($\rho_{eff}$)

$$\rho_{eff} = \frac{M_{model}}{V_{max}}$$

- $M_{model}$ - Mass of the model
- $V_{max}$ - Volume of bounding envelope
## Lattice Structures $k$ Analysis

### Surface Analysis

<table>
<thead>
<tr>
<th>Fin Type</th>
<th>Surface Area (mm$^2$)</th>
<th>Volume (mm$^3$)</th>
<th>Mass (g)</th>
<th>$k_{\text{eff}}$ (W/m-K)</th>
<th>$\alpha$ (mm$^2$/s)</th>
<th>Void Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>878</td>
<td>392.00</td>
<td>1.058</td>
<td>204.90</td>
<td>84.32</td>
<td>0.000</td>
</tr>
<tr>
<td>Dode Medium</td>
<td>934</td>
<td>49.96</td>
<td>0.135</td>
<td>11.04</td>
<td>35.64</td>
<td>0.873</td>
</tr>
<tr>
<td>Dode Thick</td>
<td>1240</td>
<td>97.54</td>
<td>0.263</td>
<td>22.54</td>
<td>37.28</td>
<td>0.751</td>
</tr>
</tbody>
</table>
Lattice Structures $k$ Analysis

Effective Thermal Conductivity vs. Void Fraction

TFAWS 2019 – August 26-30, 2019
Modeling Shortcomings

• Models which contain lattice only come in .stl (Standard Tessellated Language) format
  – .stl (Right) is a specialized file type for 3D Printers
  – Converts a CAD solid into a hollow shape bounded by triangles with a normal direction

• Computationally expensive
  – Radiation effects are difficult to usefully incorporate
  – Convection/CFD has not been attempted, could be problematic

• Limited material property data (traditional properties are unreliable)
Experiment Parameters
- Flow rate (m³/hr) of water at 16°C with a pressure drop across a valve of 1 bar
- Convection uses packed bed model

Measured Quantities:
- Convective Heat Transfer Coefficient (h)
- Flow Coefficient ($K_v$) ($C_v = 1156 \cdot K_v$)
Flow coefficients of lattice types \( (C_V = 1156 \cdot K_V) \)
Convective heat transfer coefficients of lattice types
• Internal funding was obtained at Marshall Spaceflight Center (MSFC) to experimentally measure the $k$ through lattice structures and non-fully dense solids

• The experiment will create a capability unique to MSFC

• This experiment is currently in the design/procurement phase
Other Additive Manufacturing Work

• Lattice Structures
  – Mechanical testing
  – Fracture toughness research
  – Lattice infiltration
  – Study with topologies provided by Autodesk Netfabb

• Functional Parts
Proposed Thermal Work

- 3D Printed Cryogenic Strut
- AM Thermal Property Database
- Further Convection Testing
- Enhancement of Thermal Modeling Techniques

Circle Perforated

Square Perforated

Triangle Perforated

Circle-X Perforated
$y = 149.84x^2 - 352.19x + 203.31$

$y = -207.8x + 208.88$

Effective Thermal Conductivity (W/m·K) vs. Void Fraction

Legend:
- Solid
- Medium Lattice
- Thick Lattice
- Circle Perforated
- Square Perforated
- Triangle Perforated 1.7
- Circle-X Perforated
- Dummy ~0.2 VF Fin
- Ghost Fin
- Circle-XX
- Ribbed 05
- Ribbed 10
- Ribbed 15
- Ribbed 20
- Ribbed 25
- Ribbed 30
- Ribbed 02
- Ribbed 40
- Poly. (Perforated)
- Linear (Ribbed)