Influence of porosity on the conductivity of selective laser melted stainless steel [1]
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Introduction

- The thermal conductivity of a material may vary significantly from the nominal value; therefore, being able to estimate the thermal conductivity of a material becomes important for thermal applications.
- The approach to estimate thermal conductivity developed in [2] was applied to 1.4 to 7 % porosity selective laser melted stainless steel specimens.

Background

- Additively manufactured (AM) parts are increasingly being used in thermal applications to reduce weight and increase performance [3,4].
- The quality of an AM part is highly dependent on the process parameters used and could cause unintended increased porosity in the final part.
- The change in porosity can cause the conductivity to vary significantly from the nominal value.
- Two build directions with two variants of process parameters (scan speed and hatch spacing) yielding four porosities were used to qualify the proposed method.

Four Point Method

- The electrical conductivity can be shown to be directly proportional to the thermal conductivity [5].
- The electrical conductivity results were used to corroborate the thermal conductivity results.
- The setup was performed following NIST 1531 [6].

Thermal Conductivity Estimation

Governing equation [2,7]:

\[
\frac{\partial \theta}{\partial t} = \kappa \frac{\partial^2 \theta}{\partial x^2} - \nu \theta
\]

where,

\[
\kappa = \frac{k}{\rho c}
\]

Boundary conditions:

\[
\frac{\partial \theta}{\partial x}(0, t) = -p(1 - e^{-\alpha(t + \tau)}) + \frac{\partial \theta}{\partial x}(L, t) = 0
\]

Solution to the governing equation:

\[
T(x, t) = T_0 + \frac{P}{\beta_n} \left( e^{-\beta x} - e^{-\beta L} + (\nu - \beta)(1 - e^{-\alpha(t + \tau)}) \right)
\]

where,

A Cross-sectional area
\(c\) Specific heat
\(h\) Heat transfer coefficient
\(L\) Length of the rod
\(P\) Steady state power into the rod
\(s\) Perimeter
\(t\) Time

Results

- The AM specimens were prepared and had a porosity range from 1.4 to 7 % porosity.
- The resulting measured porosity varied from the intended porosity due to build characteristics.
- The AM specimens were also compared to a wrought stainless steel specimen.
- The results show that the conductivity decreased with increased porosity.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>SS 304L</th>
<th>(X_{10})</th>
<th>(X_{90})</th>
<th>(Y_{10})</th>
<th>(Y_{90})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>8030</td>
<td>7813 ± 209</td>
<td>7392 ± 149</td>
<td>7829 ± 206</td>
<td>7757 ± 202</td>
</tr>
<tr>
<td>Porosity</td>
<td>%</td>
<td>16.0 ± 20.0</td>
<td>6.90 ± 0.14</td>
<td>1.40 ± 0.20</td>
<td>2.31 ± 0.20</td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>W/mK</td>
<td>15.42 ± 0.16</td>
<td>14.39 ± 0.09</td>
<td>12.97 ± 0.05</td>
<td>14.52 ± 0.06</td>
<td>14.06 ± 0.06</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td>MS/m</td>
<td>1.392 ± 0.017</td>
<td>1.352 ± 0.014</td>
<td>1.132 ± 0.012</td>
<td>1.369 ± 0.015</td>
<td>1.332 ± 0.014</td>
</tr>
</tbody>
</table>

Conclusions

- The results demonstrated that thermal conductivity decreases with increasing porosity and was corroborated by a corresponding reduction in electrical conductivity.
- From the results, there is a dependency on process parameters used (build direction, scan speed, and hatch spacing) and overall performance of AM parts.
- The proposed method is sensitive enough to characterize small changes of porosity in AM parts.
- The method can be further applied to evaluate other materials.

Publications