Investigation on Porosity Measurement of Polymeric Parts Produced by Laser Sintering using X-ray Computed Tomography

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Laser Sintering of Polymers

Laser Sintering (LS) is the most promising Additive Manufacturing (AM) process to become a real manufacturing process.

However, due to the complexity of the process, the porosity levels of the laser sintered parts is still high.

Information about the porosity present, the pores size distribution and the pores volume distribution within the part allow to get a feedback about the quality of the process, giving insight on how to improve it.
Computer Tomography (CT) allows to get information about the porosity of a certain part in a non-destructing way.

However, the CT scanning parameters strongly influence the imaging of the sample, affecting the further operations applied to the CT dataset and consequently the results about the porosity measurement.

In this work, the influence of the CT scanning parameters and the size of the test object on the porosity measurement are discussed.
1. Sample volume should be representative of the laser sintering process
   Typical process layer thickness: 100-120 microns \(\rightarrow 83 \div 100\) Layers

\[10\text{ mm} / 0.3\text{ mm} \approx 33 \text{ Vectors/Layer}\]
2. Sample size small enough to achieve a sufficient magnification during the CT scan, which allows to measure also the smaller pores.

High number of small pores, but low contribution to the total volume.
## Porosity Measurement Protocol

**CT Scanning Parameters Tested**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Material</strong></td>
<td>Cu, Mo</td>
</tr>
<tr>
<td><strong>Voltage (kV)</strong></td>
<td>60, 70, 90, 110</td>
</tr>
<tr>
<td><strong>Tube Power (W)</strong></td>
<td>14 (low), 18 (high)</td>
</tr>
</tbody>
</table>

* 1500 projections, 1415 ms exposure time, 9 micron voxel size
Porosity Measurement Protocol
Analysis of the CT datasets

1. **Image Quality**: calculation of Contrast-to-Noise-Ratio (CNR) and Signal-to-Noise-Ratio (SNR) on representative reconstructed slices.

2. **Porosity**: Calculation of porosity (VGstudio max 2.0), pores count distribution and pores volume distribution.

3. **Pore Morphology**: comparison between images of the same pore.
Contrast-to-Noise-Ratio (SNR)

Higher CNR with Mo target

\[ CNR = \frac{\mu_{\text{material}} - \mu_{\text{background}}}{\sigma_{\text{background}}} \]
Signal-to-Noise-Ratio (SNR)

Higher SNR with Mo target

\[ SNR = \frac{\mu_{\text{material}}}{\sigma_{\text{background}}} \]
Pores Count Distribution
Influence of Tube Power

A higher power leads to a lower number of small pores measured.
Pores Count Distribution
Influence of Tube Power

A higher power determines a shift of the pore count distribution to smaller pores sizes (decrease in pore size measured)
Pores Volume Distribution
Influence of Tube Power

A higher power determines a lower measured volume for the bigger pores
The increasing in tube power determines an enlargement of the source focal spot, leading to a more severe blurring effect, probably responsible for the decrease in the pore size measured.


For the low power the porosity calculated is almost independent from the voltage.
Pore Morphology
Effect of Voltage

Low power

High power

60 kV  70 kV  90 kV  110 kV

60 kV  70 kV  90 kV  110 kV

Raw images

Binary Images*

* Otsu threshold algorithm
Second Part of the Study
Influence of the number of projections

<table>
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<th>Levels</th>
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<tr>
<td>Target Material</td>
<td>Mo</td>
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<td>Voltage (kV)</td>
<td>60**, 70, 90, 110</td>
</tr>
<tr>
<td>Tube Power (W)</td>
<td>14 (low)</td>
</tr>
<tr>
<td>Number of projections</td>
<td>1500, 3000</td>
</tr>
</tbody>
</table>

* 1415 ms exposure, 9 micron voxel size.

** The scan at 60kV with 3000 projections, has not been carried out due to an error in the system.
Contrast-to-Noise-Ratio (CNR)
Signal-to-Noise-Ratio (SNR)
A higher number of projections helps to get rid of the noisy pores.
Pore Count Distribution

Effect of Number of Projections

Pore Count vs. Pore Diameter (micron)
Pore Volume Distribution
Effect of Number of Projections
Porosity Calculated by VG

Increasing the number of projections leads to a lower measured porosity, mainly due to the lower number of ‘noisy pores’ present.
Pore Morphology
Effect of increasing the number of projections

Increasing the number of projections leads to a lower noise

* Otsu threshold algorithm
Conclusion

• Within the set of parameters investigated, Mo target gives a higher CNR and SNR
• The higher power level investigated leads to a decrease in the pore size and porosity measured, probably due to an enlargement of the electron beam focal spot
• Higher voltages allow to get more information about pore morphology
• Using a higher number of projections improve the CNR and SNR, due to the lower noise in the datasets. This leads also to a lower number of smaller pores detected (‘noisy-pores ‘ eliminated)
Acknowledgments

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