Project Background

Inconel 718 is a widely used Ni-based superalloy that is favorable for harsh environments due to its corrosion resistance, strength, weldability, and ductility. It is ideal for use in additive manufacturing projects in applications such as gas turbine components, combustors, turbocharger rotors, etc.

Laser powder bed fusion is often used as an additive manufacturing technique for Alloy 718.

Oxide dispersion strengthening increases the mechanical properties of a material through the dispersion of small oxide particles [2].

Project goal: investigate the effects of nano yttrium oxide particles on microstructure and mechanical behavior of AM Alloy 718 and compare the properties of AM Alloy 718 with a control sample size distribution (PSD) (15-45 μm), wide particle size distribution (10-63 μm), and a wide particle size distribution alloyed with 1.5 wt% yttrium oxide particles.

Materials

Alloy 718: Samples were printed using a control PSD powder, a wide PSD powder, and a wide PSD powder with 1.5 wt% yttria added. All powders produced via laser powder bed fusion with a 0.200 kgf vibratory milling machine.

Yttria: Nanoparticles of yttrium oxide were milled into 718 powder using YSZ cylindrical 10mm media for 1hr.

Design of Experiments (DOE): Laser power and scanning speed used in printing can be seen in the table below. Layer thickness (d) was 0.11 mm and the hatch spacing (h) was 40 μm. Examined specimens highlighted in yellow. Laser energy (E) is below on the right.

Experimental Procedure

Powder Preparation: For the yttria added samples, 1.5 wt% of 30-40 μm yttria oxide powder was added to the 10-63 μm 718 powder. It was then milled using a Vibratom vibratory milling machine and cylindrical YSZ media.

Optical Microscopy: An Olympus BX41M optical microscope was used to examine the XY faces of the polished samples. Porosity was determined using grayscale thresholding on ImageJ with a threshold value of 100.

Scanning Electron Microscopy (SEM): Backscatter detection and energy dispersive X-ray spectroscopy (EDS) were carried out by using a Quanta 650 SEM at 15 KV and a spot size of 5.5.

Uniaxial Tensile Testing: Samples were printed and then cut to a dog bone shape. Polishing was done to 2000 grit to remove any surface imperfections. Tensile testing crosshead speed was 0.75 μm/s.

Vickers Microhardness: Each sample was tested 10 times with a 0.200 kgf pyramidal diamond indenter with a 13 second dwell time using a Wilson Hardness Tuken 1202. The average of the diagonal lengths were used to calculate the Vickers hardness value.

Microstructure Analysis

Optical Microscopy

Optical Micrographs revealed two types of porosity in 718: ceramic inclusions (red) and natural porosity in 718 matrix (blue). A table of the % porosity for each sample (XY plane) is below.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Control PSD</th>
<th>Wide PSD (% porosity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.3 ± 1.3</td>
<td>3.0 ± 0.03</td>
</tr>
<tr>
<td>B</td>
<td>1.8 ± 0.7</td>
<td>2.5 ± 0.03</td>
</tr>
<tr>
<td>C</td>
<td>3.3 ± 0.3</td>
<td>4.0 ± 0.03</td>
</tr>
<tr>
<td>D</td>
<td>3.0 ± 0.5</td>
<td>4.0 ± 0.03</td>
</tr>
<tr>
<td>E</td>
<td>3.0 ± 0.5</td>
<td>4.0 ± 0.03</td>
</tr>
</tbody>
</table>

Ceramic inclusions were not seen in the wide or control group samples. Inclusions are likely agglomerated yttria or contamination from milling at Praxair.

SEM: EDS

EDS revealed that some of the porosity shown in optical images were actually inclusions of yttria, oxygen, and zirconia which can be seen from the scan area above. These inclusions could be sourced from the YSZ milling media used in the high energy vibratory powder milling process which could have led to a degradation of the milling media. The scan also shows that the Ni, Cr, Fe, and Nb are well distributed throughout the sample.

SEM: Backscatter

Backscatter imaging revealed a cellular structure to the sample typical with additively manufactured metals. Closer inspection shows nanoparticles on the grain boundaries of the cellular structure. These lead to ODS strengthening.

SEM: EBSD

EBSD imaging of all control and wide samples revealed elongated grain structure in the build (a) direction. Grain size measurements revealed no clear grain size difference between the control and wide samples. Yttria added samples showed a more equiaxed grain structure.

References