Characterization of Direct Metal Laser Melted Yttrium Oxide Dispersion Strengthened Ni-Cr Superalloys Parts for Launch System Applications

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Direct Metal Laser Melted Inconel MA 754 was microstructurally and mechanically characterized. EDS and EBSD show the presence of Cr3C2 carbides, a Ni3Y phase uncharacteristic of MA 754 and preferential grain growth in the build direction. An annealing trial showed progressive recrystallization at a range of temperatures. Creep and tensile trials indicate the material obeys three-phase creep behavior and meets expected performance. Fracture surface examination showed brittle fracture and lack of fusion within the build. Future work includes improving powder development and developing hot isostatic pressing parameters to improve build fusion.

Project Background
Direct Metal Laser Melting (DMLM) Inconel MA 754 parts are being explored for aerospace applications. Inconel MA 754 is an Oxide Dispersion Strengthened superalloy known for its exceptional mechanical properties and corrosion resistance at high temperatures due to the presence of Yttria (Y2O3). DMLM selectively melts powder in layers to create bulk parts with complex shapes.

Experimental Procedure
Experiments were designed to characterize the annealing behavior, tensile properties and creep resistance of additively-manufactured (AM) samples. Effectiveness was gauged using hardness and grain size measurements. Microstructure and composition of all samples were characterized using scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), energy dispersive spectroscopy (EDS), and X-ray diffraction (XRD). Fractography was conducted using SEM on tensile samples.

Results & Discussion (cont.)

As-Built Composition and Phases

<table>
<thead>
<tr>
<th>Ni</th>
<th>Cr</th>
<th>Fe</th>
<th>C</th>
<th>Al</th>
<th>Si</th>
<th>Ti</th>
<th>O</th>
<th>Y</th>
<th>Wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>20</td>
<td>1</td>
<td>0.05</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
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EDS and EBSD indicate the presence of M23C6 carbides, a Ni3Y phase, and a Ni-Cr matrix. Y and O were detected but not present in fine Y2O3 dispersoids. The presence of Si and decreased amount of Ti and Al indicate inadequate processing.

Heat Treatment

Tensile strength of as-built MA 754 aligns with that of hot-extruded material, particularly with fine grain morphology. Three phase creep behavior was verified.

As-Built

Nasa

Heat Treated

(1350°C 4hr) Purdue

Conclusions & Future Work
Analysis showed the presence of M23C6 carbides, a Ni3Y phase, and poorly dispersed Y2O3. A combination of lowered hardness values and change in grain morphology indicate recrystallization. As-built tensile fracture surfaces showed brittle fracture, lack of fusion, and presence of unmelted powder. Tensile testing showed lower strength at room temperature (though higher than fine-grained MA 754 at elevated temperature) than expected, indicating printing defects are present but do not affect elevated temperature mechanical properties as much as expected. Creep resistance and as-built tensile matched expectations, encouraging that continued development is viable.

Future work includes improving powder processing, optimizing the oxide content to ensure optimal Y2O3 content. This analysis encourages future use of hot isostatic pressing of the as-built MA 754 parts to encourage a higher degree of fusion and reduce porosity.

Results & Discussion (cont.)

Mechanical Testing

<table>
<thead>
<tr>
<th>Yield Stress (MPa)</th>
<th>UTS (MPa)</th>
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Comparison to literature suggests initial creep testing occurred in low creep exponent region where fracture by cavitation was expected.

Sources