Investigation of 3D Printed Alloy 718 with Oxide Dispersion

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Abstract: To improve the high temperature mechanical properties of 3D printed nickel-based superalloy (Alloy 718), the use of oxide dispersion was investigated. A small amount of yttria particles were ball milled into the Alloy 718 matrix. Their microstructure and mechanical properties were examined and compared with the 3D printed Alloy 718 without oxide particles. The addition of yttria oxide did not result in cracking or a loss of ductility. A more significant strengthening effect is anticipated if the size of oxide particles can be reduced further.

Project Background

Laser powder bed is an additive manufacturing technique used for 3D printing that uses a layer deposition process to melt a metal powder material. Laser energy density is an empirical metric used to measure the optimal powder parameters for 3D printing.

Alloy 718 is a nickel-based superalloy that is commonly used in the aerospace industry, highly weldable, and strong. At high temperatures, Alloy 718 needs increased creep resistance and mechanical strength. Incorporating oxide particles into the Alloy 718 matrix will fulfill these needs. There is a risk of losing ductility and creating cracks if the oxide particles are improperly introduced.

The project goal is to strengthen Alloy 718 with oxide dispersion strengthening (ODS), ODS consists of two possible strengthening mechanisms, dislocation pinning and defecting crack propagation.

Materials

Alloy 718: Metal powder produced by gas atomization with a particle size of 30 – 50 μm was used for printing parts. Powders were produced by Praxair using their typical production parameters.

Yttrium Oxide: Particles of yttria were ball milled into the Alloy 718 powder at 1 wt%. Particle size ranges from approximately 1 – 5 μm.

Design of Experiments (DOE): The equation for calculating laser energy density is shown to the right. The thickness (d) of each layer of particles is 0.11 mm and the hatch spacing (h) was held constant at 40 μm.

Specimens examined are highlighted in yellow.

Experimental Procedure

Laser Bed Printing: EOS 290 laser 3D printer used for production of samples is shown on the right.

XRD was performed with the Bunker D8 Focus diffractometer with a 2θ scan from 30° to 90° using a Cu Kα wavelength emission of 1.54056 Å to prospect for general peak locations.

Scanning Electron Microscopy (SEM): Both the cubic and dogtoe samples were examined with a Quanta 650 scanning electron microscope.

Energy Dispersive X-Ray Spectroscopy (EDS) analysis is also performed, to investigate the chemistry of the samples and locate the yttria particles.

Uniaxial Tensile Testing: Tensile bars with the dimensions seen to the right were mechanically tested with a crosshead speed of 0.001 m/min.

Vickers’ Microhardness: An AHM55 Automatic Hardness Testing System indented nine measurements into each XY plane of cubes with varying printing parameters and a 200 g force. The average length between the diagonals of each indent was used to determine a Vickers Hardness Number.

Microstructure Analysis

XRD: XY planes scanned

SEM: Microstructure Comparison

The SEM imaged revealed that after adding Y2O3 no significant cracking was introduced to the system. Cellular structure was also observed in these samples.

EDS: Y2O3 Detection

The EDS analysis confirmed the presence of the Y2O3, indicating that Y2O3 particles can survive the high processing temperature.

Y2O3 Morphology

The morphology of the oxide particles depends on the printing parameters. The printing parameter E (900 mm/s, 285 W) leads to the smallest and spherical oxide particles. Whereas, agglomeration of yttria occurs when applying other printing parameters.

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Mechanical Properties

Uniaxial Tensile Testing

Figure (right): Engineering stress vs engineering strain for tensile bars with 1 wt.% yttria. The 718+1wt% Y2O3 Additive Manufacturing Alloy 718 printed at position E. Figure (below): plot of 0.2% offset yield strength with respect to scan speed and laser power. The red arrow shows the trend.

Table: Calculated mechanical properties for tensile specimens with 1 wt.% yttria (see DOE) and pure 718 with E position print parameters.

Microhardness Tests

An indentation (right) on the surface of a cube sample describes the hardness of the material. A greater average diagonal length is indicative of a softer material. The microhardness is typically three times that of the flow stress, which is depicted in the table below.

Conclusions

- The addition of oxide inclusions was successful and did not compromise the mechanical properties of laser printed Alloy 718.

- The optimal laser parameters for printing Alloy 718 with yttria particles is a scan speed of 960 mm/s and laser power of 285 W, which can limit the presence of unmelted powders and agglomerated yttria particles.

Recommendations

- The team advises future studies to add nano-sized yttria particles to Alloy 718 to improve the mechanical properties.

- Apply a scan speed of 960 mm/s and laser power of 285 W for future 3D printing parameters to minimize defects.

Reference
