

Additive Manufacturing Process Development DOE for NASA HR-1 using Laser Blown Powder Directed Energy Deposition

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Abstract

NASA HR-1 is a Fe-Ni-Cr alloy that is used for high pressure hydrogen applications such as rocket engines, energy, and oil and gas. This investigation was focused on conducting a design of experiment program aimed at mapping the parameter process window for NASA HR-1 using the laser blown powder directed energy deposition (LP-DED) process. A two phased design of experiments (DOE), the first phase of the experiment was focused on optimizing single bead tracks while the second phase of the experiment was focused on optimizing bead overlap hatching in a multi pass bead build up. During the first phase of the deposition parameters, namely laser power, travel speed, and powder feed rate were varied. A down selection from the single bead parameter set was made and hatching experiments were conducted that focused on the overlap distance. In this paper the approach for conducting the DOE and results are discussed. The results focused on measurement of bead geometry, the as-built microstructural evolution, and porosity within the samples. The team at MSFC saw a variety of results across the process map created during the first phase of experimentation and were able to down select a parameter that created an optimal bead shape with a minimal amount of build porosity. It was determined that laser power and robot travel speed were the most sensitive parameters. The results from this investigation will inform future laser powder directed energy deposition parameter developments.

Introduction

NASA HR-1 is a gamma prime strengthened Fe-Ni-Cr superalloy developed for high strength, hydrogen embrittlement resistance, weldability, and by extension has enhanced printability with regard to additive manufacturing (AM)[1,2]. This alloy was developed at the NASA at Marshall Space Flight Center (MSFC) by Chen et. Al. as an alternative to A286 and JBK-75[3]. NASA HR-1 was designed to have increased thermal conductivity, fatigue resistance, yield strength, elongation, resistance to weld related cracking, and hydrogen environment embrittlement (HEE) resistance (HEE)[3]. These properties make NASA HR-1 a good candidate for use in liquid rocket engine components such as nozzles that utilize liquid hydrogen as a propellant. One potential application is the RS-25 engine utilized on the Space Launch System (SLS) for NASA's Artemis missions [4]. The RS-25 is based on the heritage space shuttle main engine (SSME), which heavily utilizes JBK-75 for its HEE resistance[5,6].

NASA HR-1 was initially produced using traditional manufacturing methods, specifically Vacuum induction melting (VIM) and vacuum arc remelting (VAR) followed by hot and cold rolling to final product form [4]. Starting in 2019, NASA started investigating AM NASA HR-1 for its use on complex, long lead time components for rocket engines [5]. NASA HR-1 was adopted as a good candidate for AM as it was designed to be resistant to weld related cracking, which translate to an improved printability when used in AM compared to its alternative JBK-75/A286 [4,5].

NASA HR-1 has been advanced using powder and wire feedstock and AM processes including laser powder bed fusion (L-PBF), Laser Powder Directed Energy Deposition (LP-DED) and Arc Wire Directed Energy Deposition (AW-DED) [4,7,8]. Many of the components that use NASA HR-1 are large, which