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Process Development for Haynes® 282® Using Additive Manufacturing

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OAK RIDGE NATIONAL LABORATORY
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Materials Science & Technology Division
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Process Development for Haynes® 282® Using Additive Manufacturing

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ABSTRACT

ORNL, in collaboration with Haynes International successfully demonstrated the ability to process the nickel-base superalloy Haynes® 282® for additive manufacturing using electron beam melting (EBM). The EBM processed Haynes® 282® material was found to exhibit favorable microstructure and mechanical properties when compared to traditional wrought product.

1. PROCESS DEVELOPMENT FOR HAYNES® 282® USING ADDITIVE MANUFACTURING

This phase 1 technical collaboration project (MDF-TC-2016-088) was begun on July 1, 2015 and was completed on July 1, 2017. The collaboration partner Haynes International is a large business. The efforts of this technical collaboration focused on developing the processing science for Haynes® 282® in the electron beam melting process and demonstrated favorable microstructure and mechanical properties when compared to traditional wrought product.

1.1 BACKGROUND

Additive Manufacturing's (AM) promise and potential is of growing interest to industries across the US such as aerospace, energy, automotive, and medical. Haynes® 282® is a newly developed nickel-based superalloy from Haynes International, which represents an opportunity for a printable high temperature alloy alternative for AM. Alloy 282® has numerous applications for land-based turbines with the added benefit of superior high temperature creep strength compared to other Ni-base superalloys currently being considered for AM. Haynes® 282® is gamma-prime strengthened, and lacks the niobium content which gives rise to meta-stable phases as in Alloy 718 when using the Electron Beam Melting (EBM) powder bed technology. Unwanted phases such as Delta that are precipitated in Alloy 718 are not expected to form in Haynes® 282® because of its composition. The absence of these phases may simplify, or eliminate, the need for thermal post-processing fabricated parts (though some aging may be required to obtain peak-hardness).

1.2 TECHNICAL RESULTS

1.2.1 Haynes® 282® Process Parameter Development

Three builds consisting of 16 density cubes each were fabricated using an Arcam S12 EBM machine to investigate the sensitivity of key electron beam melting process parameters (speed function, hatch spacing, line order, and focus offset) to the obtainable density of the Haynes 282® material. Post-fabrication porosity measurements were performed along the build direction of each sample from the builds. Illustrated in Figure 1 are representative examples taken from the builds which reveal the high (99.5%) and lows (97.9%) of the process-induced porosity observed for the process window examined. In the context of AM materials, a density of 99.5% is considered comparable to other Ni-base superalloys, with some room for further improvement. Further, the material did not exhibit any indications of cracking or other defects associated with solidification.

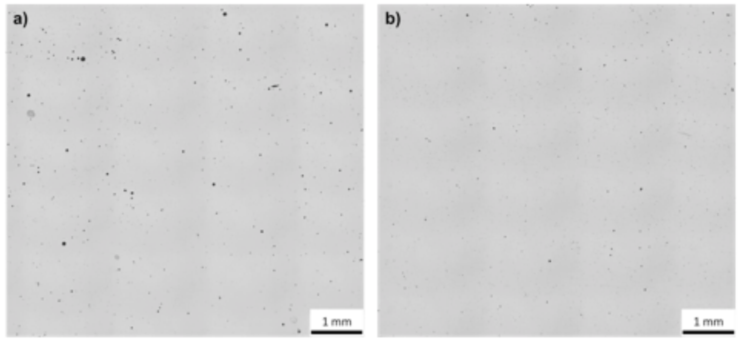

Figure 1: Comparison of process-induced porosity within Haynes 282 alloy fabricated using EBM a) Focus off-set=5mA, Speed Function=75, Hatch Spacing=0.1mm, Line Order=1 to yield 97.9% dense material b) Focus offset=2mA, Speed Function=55, Hatch Spacing=0.125mm, Line Order=1 to yield 99.5% dense material

1.2.2 EBM Haynes® 282® Microstructure Characterization

The as-fabricated EBM microstructure was characterized using a scanning electron microscopy (SEM) analysis. Among the phases observed were primary carbides and gamma prime strengthening precipitates. Illustrated in Figure 2 are inter- and intragranular carbides observed in EBM Haynes 282®. Intragranular carbides were observed to be randomly distributed and mainly associated with Ti and Mo. Energy-dispersive X-ray spectroscopy provided confirmation that the carbides are primarily of the MC-type. Moreover, the grain boundary carbides exhibited two types of morphology: blocky and film-like. Their composition was mainly associated with Cr based upon Energy-dispersive X-ray spectroscopy (EDS) measurements.

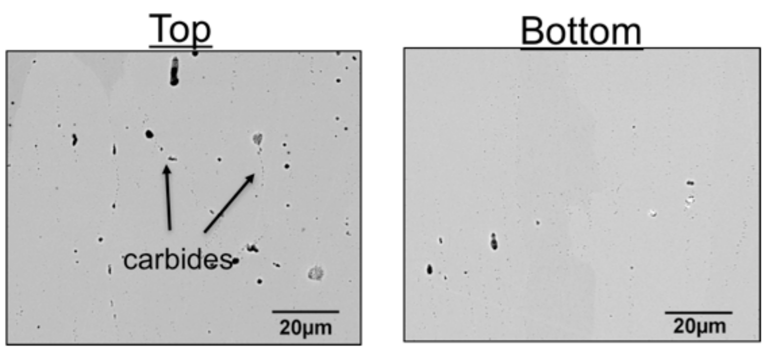

Figure 1: Scanning electron back scatter electron images of carbides observed in EBM Haynes 282 acquired at the top and bottom of the build.

Evaluation of the γ′ distribution and morphology was performed along the build direction. The γ′ distribution was observed to be relatively uniform, with no depletion along grain boundaries observed (Figure 3). Near the top of the as-fabricated samples, the γ′ was observed to exhibit a spherical morphology (Figure 3), whereas near the bottom of the samples the γ′ took on a cubodial morphology. This a function of the time at temperature the initial layers at the bottom of the samples spent at temperature during the entire build process.

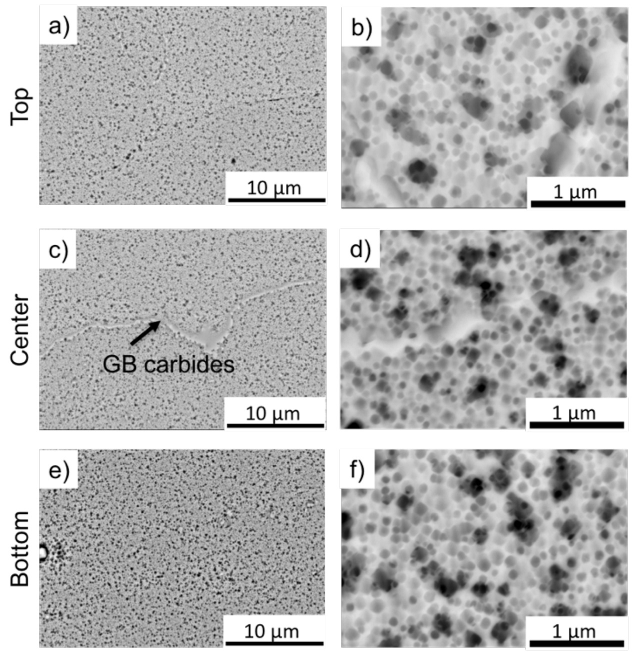

Figure 2: BSE images of the microstructure showing the spatial variation of the γ/ precipitate size and morphology in EBM Alloy 282® as a function of build height in a 10mm sample.

1.3 IMPACTS

Due to the successful processing of Haynes® 282®, the alloy now represents an alternative choice for high temperature parts produced through metal AM. Its development as an AM material may reduce variability in material properties and offer improvement in operational temperature of parts. This alloy has the ability to outperform Alloy 718 as a high-temperature material. With the success of this alloy development project, a significant success for the industrial collaborator, Haynes International, as it would push Haynes® 282® to the forefront of high-end additive manufacturing for power production via gas turbine engines.

1.3.1. Subject Inventions

There are no subject inventions associated with this CRADA.

1.4 CONCLUSIONS

Process parameter development was conducted for Haynes® 282® using the electron beam melting process. Through optimizing the process parameters, a density of 99.5% was achieved in the as-fabricated material. Additionally, the material did not exhibit any indications of cracking or other defects associated with solidification. The microstructure of the as-built material exhibited γ' in the aged and over aged states suggesting the material may require a post-process heat-treatment to optimize the mechanical performance.

2. HAYNES INTERNATIONAL BACKGROUND

Haynes International, Inc., headquartered in Kokomo, Indiana, USA, is a leading developer, manufacturer and marketer of high-performance nickel- and cobalt-based alloys used in corrosion and high-temperature applications. Our highly-trained staff and technicians provide superior customer service, worldwide technical support and one-on-one consultation in selecting the proper alloy for the application. In addition to stocking our standard product forms, our global service centers offer value-added services to shorten your cycle time, reduce material waste and increase your operation's efficiency. Haynes International is a partner in your entire material management system and provides value far beyond the alloys themselves.