Microstructure and Properties of Ni-based Components Fabricated by Additive Manufacturing

OAK RIDGE National Laboratory | MANUFACTURING DEMONSTRATION FACILITY

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BACKGROUND AND OBJECTIVES

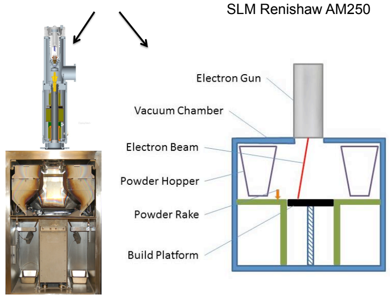
- Additive manufacturing (AM) offers the possibility to fabricate complex near-net-shape components and can result in significant savings by decreasing the cost of tooling and materials.
- The large-scale production of high-temperature high-strength components has however not yet been achieved because of the difficulty to control the final microstructure, and, thus, properties of parts made by laser or electron beam melting.
- The goal of this project is to optimize additive manufacturing fabrication processes with an initial focus on gas turbine components made of Ni-based Hastelloy (HX). The three main AM techniques, electron beam melting (EBM), laser metal deposition (LMD) and selective laser melting (SLM) will be assessed.
- In FY16, the project focused on the fabrication of EBM HX test bars using powder purchased from Praxair. Similar test bars have been fabricated with a Sandvik powder for another project, and the microstructure and tensile properties of the Praxair and Sandvik EBM HX alloys were compared.

ORNL (MDF)

The MDF gives industries access to unique research facilities and reduces their risk for adopting cutting-edge manufacturing technologies.

EBM Arcam S12

SLM Renishaw AM250



- EBM process uses a 3000 watt electron gun to build and preheat the build chamber.
- For Ni-base superalloys the EBM process occurs above 850°C. The high build temperatures minimize residual stresses within the final part and eliminate the need for stress relieving.
- EBM operates in a vacuum (<10^{-4} mbar) which eliminates impurities within the processed material.
- The ability to rapidly manipulate the electron beam allows for the formation of multiple melt pools at a given instance, thereby increasing the fabrication speed over current laser AM systems.

POWDER CHARACTERIZATION

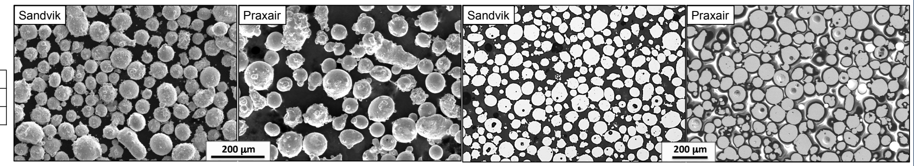
Composition (wt%)

Provider	Ni	Cr	Fe	Mo	Co	Mn	Si	W	C
Sandvik	Bal.	22	19	9	1.6	0.9	0.9	0.7	0.1
Praxair	Bal.	22	18	8.9	1.5	0.1	0.1	0.6	0.1

HX specification: Mn and Si < 1 wt%

Particle Size & Flowability

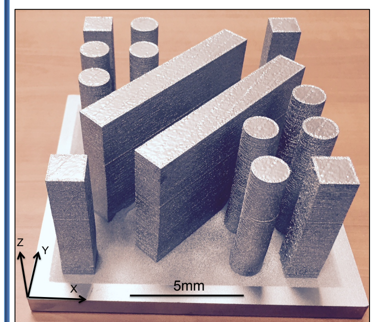
Provider	Particle Size	Flowability
Sandvick	38µm <size>106µm	17.52s/50gm
Praxair	45µm <size>125µm	17.53s/50gm



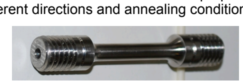
Similar particle size & morphology but significant difference in Mn and Si concentration

- Most powder particles contain large numbers of satellite particles
- Irregularly shaped particles and entrapped gases within particles consistent with powder manufactured through gas atomization process

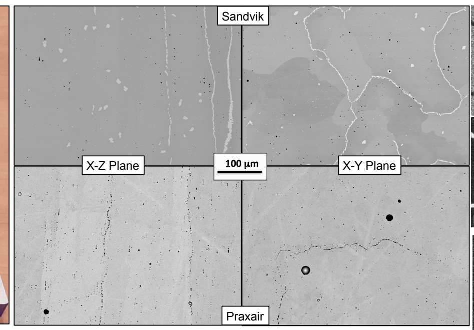
TEST BAR FABRICATION



- Bars ~3.5" tall + 3.5"x4" rectangular block
- Machining of conventional and small dog bone specimens for tensile and creep testing
- Characterization of the mechanical properties in different directions and annealing conditions



MICROSTRUCTURE CHARACTERIZATION



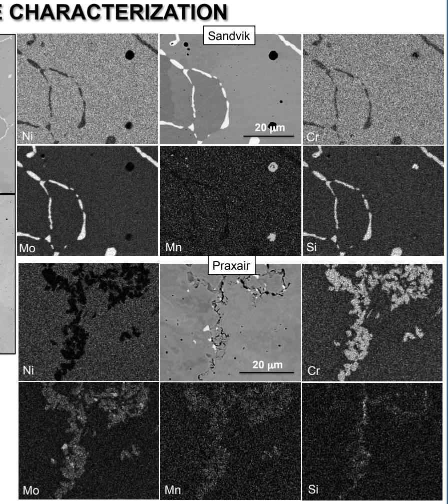
- Elongated grains along the build direction with both powders
- Presence of small voids plus few larger voids due to entrapped gases in powder

Sandvik

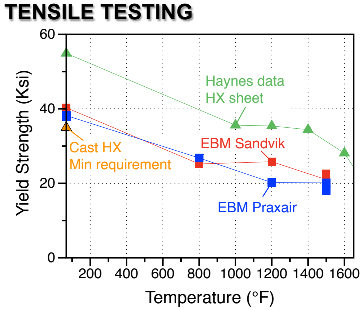
- Large (Mo,Si)-rich carbides at most grain boundaries

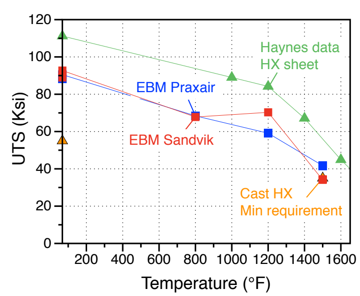
Praxair

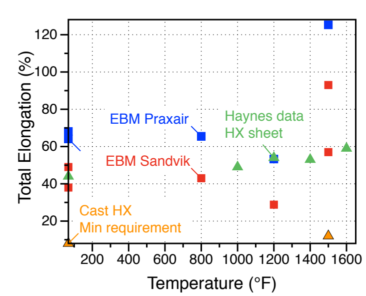
- Fewer but coarser precipitates associated with GB cracking
- (Mo,Cr)-rich precipitates with additional Si and Mn enrichments



TENSILE TESTING







Similar tensile properties for the two EBM HX alloys
Tensile strength superior to the minimum requirement for cast HX

EBM HX alloys exhibit excellent ductility in the as fabricated condition at all temperatures

SUMMARY

- **Several Hastelloy X builds were fabricated by Electron Beam Melting using two different powders**
- **Variation of Si and Mn powder concentrations had a significant impact on the resulting microstructure**
- **Both alloys exhibited excellent ductility at all temperatures and their tensile properties were superior to the minimum requirement for cast HX**
- **Future work includes fabrication of HX test bars by selective laser melting as well as creep and fatigue testing**

ACKNOWLEDGMENTS

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