Advanced Manufacturing of High-Temperature Alloy Components for Small Modular Reactors

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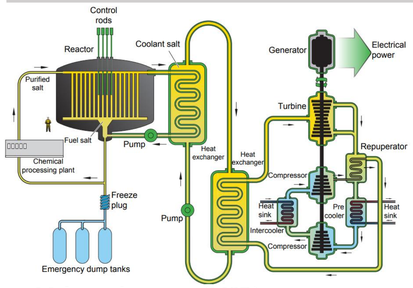
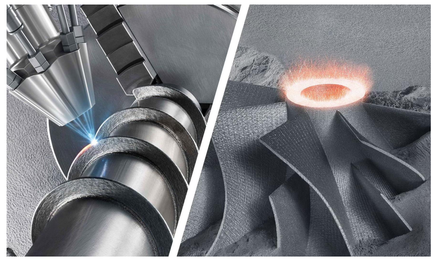
INTRODUCTION



Molten salt reactor (MSR)

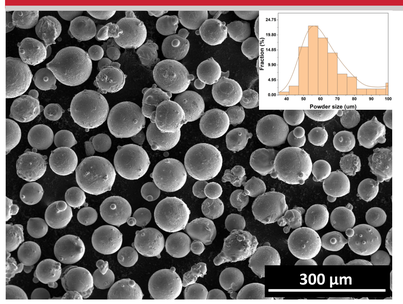
- Operating temperature: 700-800 °C
- Fuel type: Liquid/solid
- Coolant: Molten salts
- Core pressure: Near atmosphere



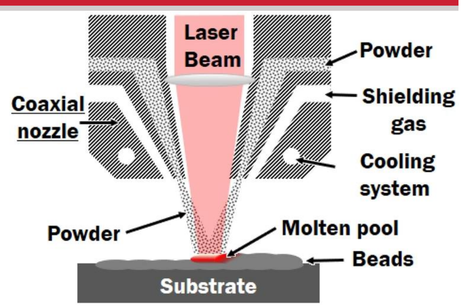
Additive manufacturing (metal 3D printing)

- Materials efficiency and waste reduction
- Design freedom and complexity
- Improved reliability and performance
- Rapid prototyping and production

MATERIAL & METHOD



SEM image of spherical 316H powders

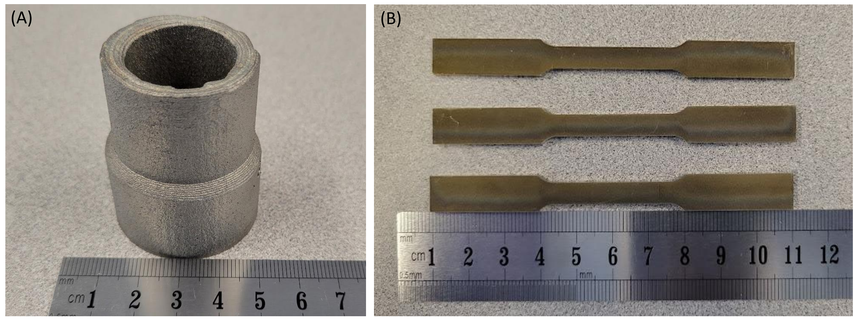


Laser-Direct Energy Deposition (L-DED) process

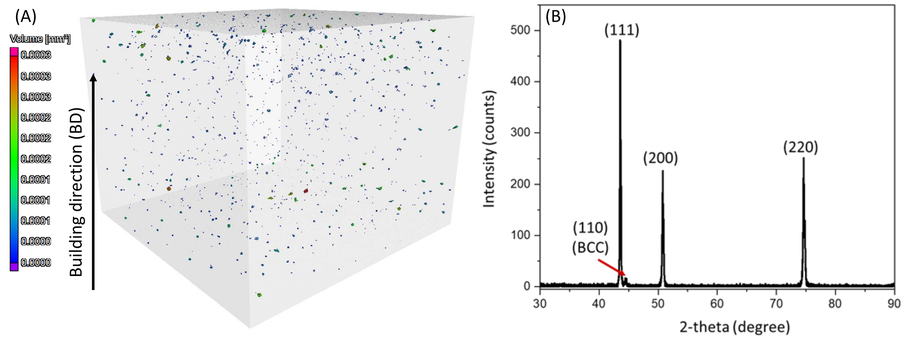
316H powder Composition (wt.%)	C	Fe	Cr	Ni	Mo	Mn	Si	O
	0.05	Bal.	17.0	12.1	2.5	1.07	0.48	0.03

L-DED parameters	Laser power	Speed	Feed rate	Layer thickness	Hatch spacing
	340 (W)	7.62 (mm/s)	6.08 (g/min)	300 (µm)	0.6 (µm)

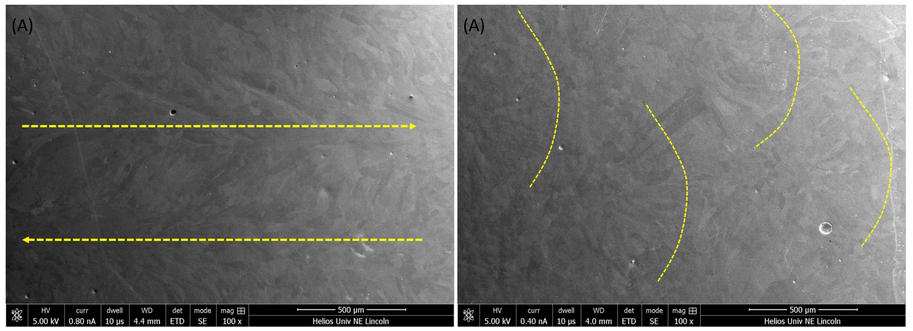
RESULTS & DISCUSSION



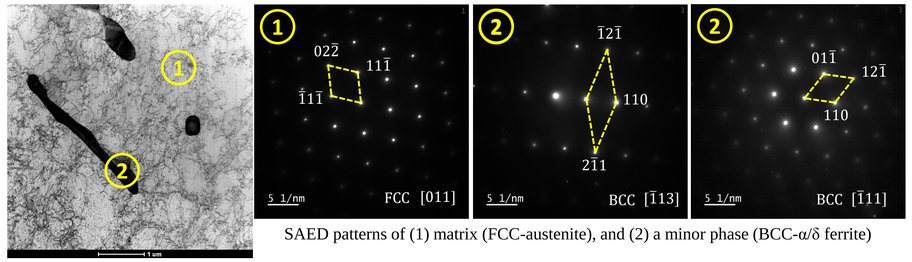
Optical images of (A) a thin-to-thick wall thickness tube and (B) dog-bond samples for tensile strength measurement of 316H fabricated using L-DED process



(A) X-ray computed tomography (XCT) of internal porosity in the printed part (porosity < 0.01 vol.%), (B) X-ray diffraction (XRD) pattern of the printed 316H, showing the major austenitic phase with a face-center cubic (FCC) crystal structure

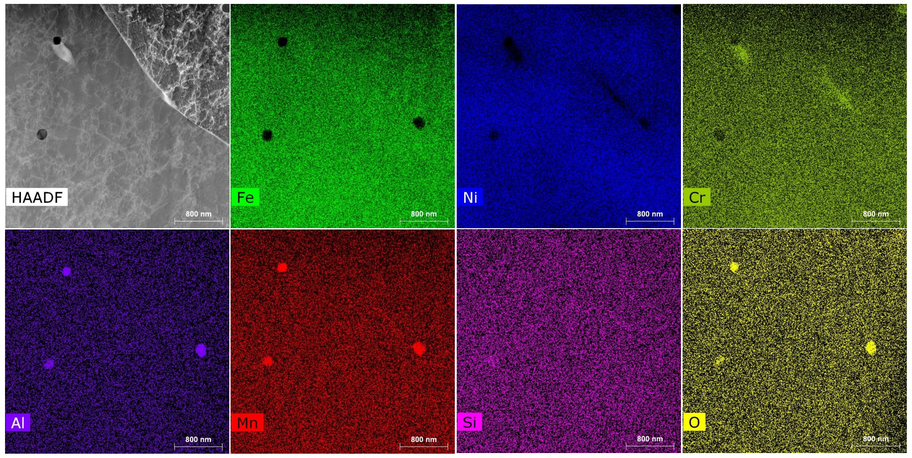


SEM images of grain structure (A) across and B) along the building direction of the L-DEDed 316H sample.

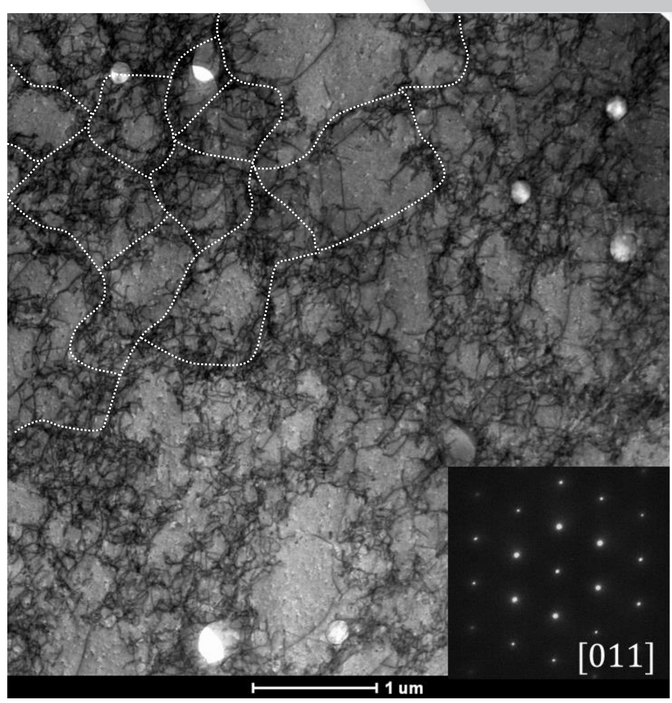


SAED patterns of (1) matrix (FCC-austenite), and (2) a minor phase (BCC-α/δ ferrite)

TEM analysis: STEM bright field image and selected area electron diffraction (SAED) patterns of the matrix and minor phase



High-angle annular dark-field (HAADF) images and corresponding STEM-EDS mapping results of the L-DEDed 316H



STEM bright-field image of dislocation cellular structure in the L-DEDed 316H (dislocation density: $1.48^{\pm 0.11} \times 10^{14}$ (m^{-2}))

CONCLUSIONS

- **Solid and intricate 316H parts with a high density (> 99.9 %) have been successfully fabricated using L-DED process.**
- **The XRD and SAED patterns reveal a major austenitic phase (FCC structure) with a minor α/δ ferrite (BCC structure).**
- **The L-DEDed sample contains (Mn, Si, Al)-rich oxide particles with a vol. fraction of 0.55% and size of 183.77 ± 38.68 nm.**
- **The sample exhibits the sub-grain dislocation cellular structure with a dislocation density of $1.48^{\pm 0.11} \times 10^{14}$ (m^{-2})**
- **The L-DEDed 316H sample will be investigated in mechanical properties as well as corrosion and irradiation resistance.**

ACKNOWLEDGEMENT

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