National Aeronautics and Space Administration

Fabrication of Turbine Disk Materials by Additive Manufacturing

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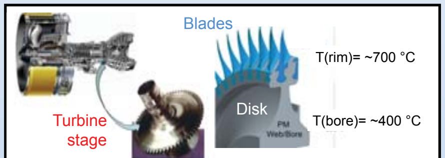
Motivation: **Powder-bed additive manufacturing may offer geometric flexibility, microstructural control and eliminate legacy tooling**

Polycrystalline Ni-based superalloy disks:

- Powder metallurgy (PM) processing developed: cost & property advantages to cast-wrought
- Powder cleanliness is critical to disk life [1]: screened for non-metallic inclusions
- High refractory content (i.e. Mo, Nb, Ta, W): more prone to thermal cracking than In718



High Pressure Hot Section of Jet Engine

Process /parameters	Electron Beam Melting (EBM)	Selective Laser Melting (SLM)
Environment	Vacuum / He bleed	Ar or N_2
Pre-heat Beam Passes	~10	None
Pre-heat Scan Speed	10^4 mm/s	n/a
Melt Scan Speed	10^2 mm/s	10^3 mm/s
Preheat Beam Current	25-30 mA	–
Melt Current or Energy	4-8 mA	100-350 W
Beam Configuration	Multiple beam	Single beam
Powder Diameters	30–100 µm	10-50 µm

Table adapted from [3]

EBM: faster build rates, elevated build temperatures, less contamination, minimal induced stress → important for disks

SLM: Smoother finishes, fewer parameters for easier control

Alloy 10 [4] powder from Homogenous Metals: 10 kg of -170 mesh, sieved by hand to +500 mesh to start EBM trials

LSHR powder from Special Metals: 180 kg of -270 mesh, 24 hours ultrasonic sieve in cleanroom facility to +500 mesh

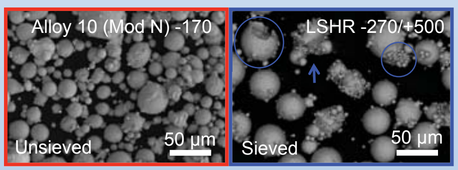
ICP: 2 run avg.	Al wt.%	Co wt.%	Cr wt.%	Mo wt.%	Nb wt.%	Ni wt.%	Ta wt.%	Ti wt.%	W wt.%	Zr wt.%	O ppm	Trace
Alloy 10 (Mod N)	3.75	15.02	10.94	2.43	0.87	56.4	0.94	3.77	5.60	0.09	190	Fe, Si, C, B
LSHR	3.50	20.55	12.46	2.67	1.46	49.7	1.54	3.46	4.38	0.05	360	Fe, Si, C, B

Two alloys similar in chemistry: LSHR had twice O pickup of Alloy 10

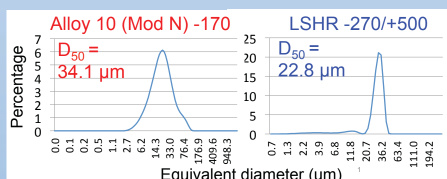
DTA in He 5 °C/min.	Solidus -°C (Heating)	Liquidus -°C (Heating)	ΔT °C	γ'-formation °C (Cooling)
Alloy 10	1257	1339	82	1168
LSHR	1240	1334	94	1127

- LSHR has wider melting range than Alloy 10
- Liquidus temperatures are within 5 °C

Powder feedstocks show differences

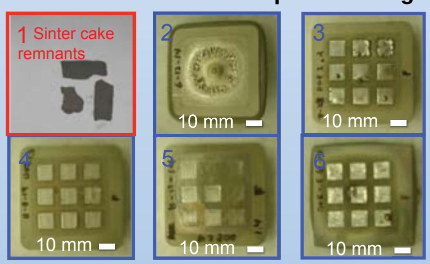


Despite careful sieving, LSHR has more particles with fine-satellites, as well as partials, irregular shaped ones



Alloy 10 powder shows a wider particle size distribution

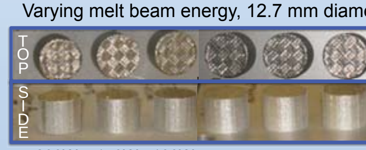
Initial EBM trials show poor melting



			Initial Preheat		Melt Preheat I (Preheat II Off, Heating Off), He=13-16 psi			
		Experiment Type	Temp °C	Time min.	Current mA	Speed mm/s	Offset mA	Results
1	A10	Preheat Test	1000	20				Good preheat, nice sinter
2	LSHR	Preheat Test	1000	20				Too hot!
3	LSHR	DOE 1.2	850	10	8.8	14600	50	Sinter ok. Smoke immediately
4	LSHR	DOE 1.3	925	10	30	14600	50	Sinter ok. Smoke immediately
5	LSHR	DOE 1.4	925	10	30	25000	80/100	Sinter ok. Smoke immediately
6	LSHR	DOE 1.5 (LSHR Plate)	925	10	30	25000	100	Over sintered bed (plate too hot). Smoke immediately

Initial LSHR SLM trials show promise

Varying melt beam energy, 12.7 mm diameter rods were fabricated at 600 mm/s



Visually 160 W rod looked the best. Optical examination along the build direction, revealed evidence of thermal cracks for some conditions, but not all (e.g. 160 W).

Major findings and future directions

- LSHR powder, despite similarities, needed a lower EBM pre-heat temp. than Alloy 10. Severe smoking was observed for LSHR in EBM trials. Smoking may result from fine satellite particles. New trials underway.
- Hand sieved Alloy 10 powder exhibited poor flow and did not rake well.
- LSHR SLM trials look promising. More characterization & trials are needed to assess thermal cracking and whether it can be averted.

References: [1] Kantzos et al., Superalloys 2004, p. 409. [2] Loeber et al., Proc Solid Freeform Fabrication, Austin TX (2011) p. 8. [3] Murr et al., J Mater Res Tech, 2012, 42. [4] Telesman et al., Superalloys 2004, p. 215.

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