NIAR®

WICHITA STATE UNIVERSITY

A qualification approach for difficult to inspect metal AM as-printed surfaces

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JAMS

Joint Centers of Excellence for Advanced Materials

Federal Aviation Administration

Project Team

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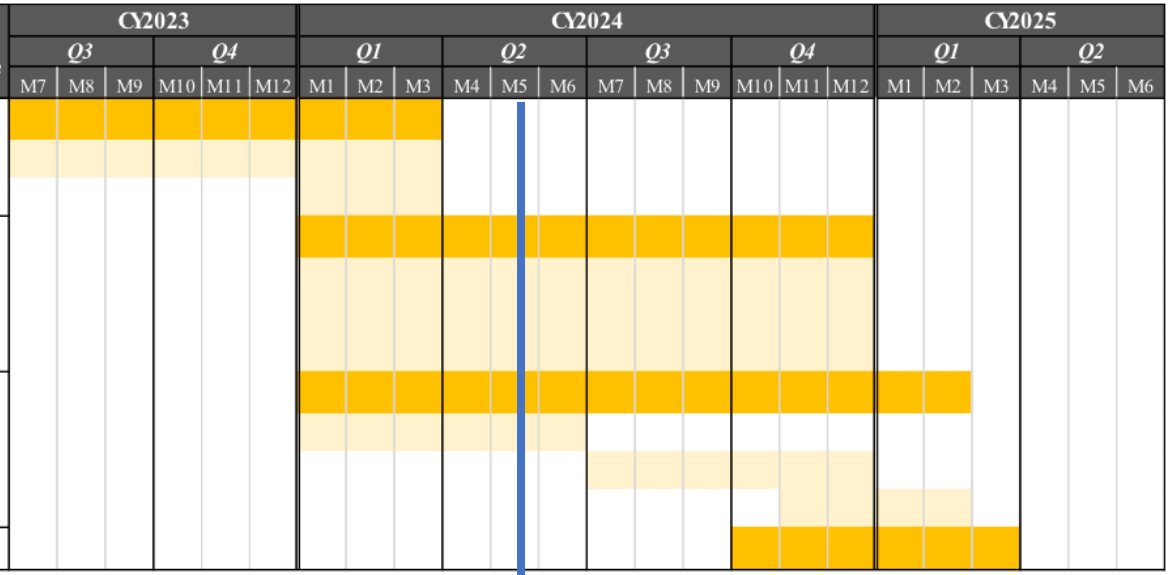
COLIBRIUM ADDITIVE
a GE Aerospace company

MAT-CS

Program Plan

Main Task	Subtasks	Percent Complete
1	Crack Generation Approach	100%
1.1	*Process Induced Crack Generation*	
1.2	*EDM Induced Crack Generation*	
2	Low-Cycle Fatigue Life Evaluation	25%
2.1	*Optimized "As-Printed" Coupons*	
2.2	*Process Induced Crack Coupons*	
2.3	*EDM Induced Crack Coupons*	
3	Nondestructive Inspection	25%
3.1	*Process Development*	
3.2	*Final Coupon Inspections*	
3.3	*POD Documentation*	
4	Design & Analysis Approach Generation	0%



Project is on Track

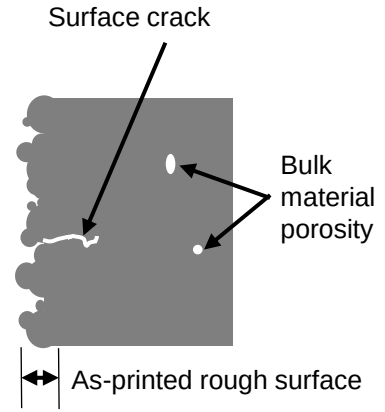
Project Background & Problem Statement

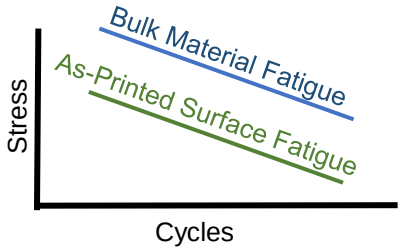
Background

- One of the primary value propositions of LBPF AM is directly printing part geometry **without secondary processing**
- As-printed rough surface impact on **fatigue is repeatable** and has been well documented.
- As-printed fatigue debit is caused by very small “crack-like” features and is **not directly related to the measured surface roughness.**
- Surface inspection methods such as **FPI is not interpretable** since the entire surface holds penetrant

Problem Statement

- **The impact of an un-inspectable surface crack beyond the printed surface roughness is unknown.**



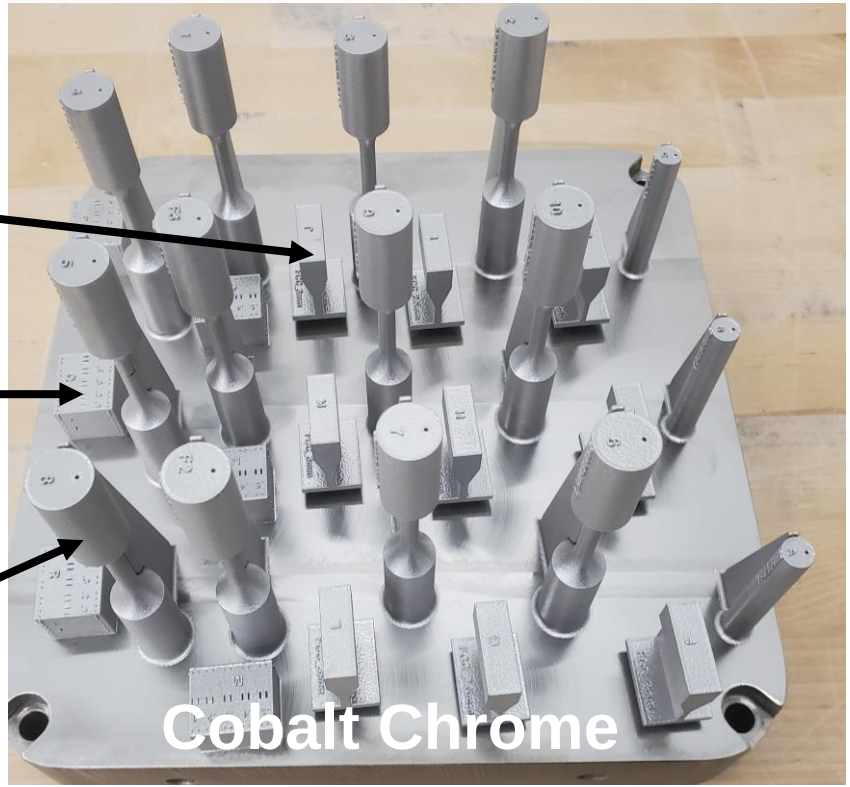


Project Overview

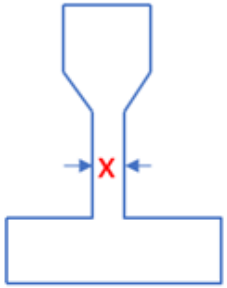
1. Research methods for creating test coupon to simulate crack on as-printed surface.
   a) Direct print method
   b) Post process machining method
2. Research methods of inspecting for crack
3. Establish interpretable crack length
4. Establish fatigue impact of surface crack which is not interpretable by inspection as compared to as-printed surface
5. Propose qualification approach for as-printed surfaces

Three Direct Print Methods Evaluated

1. Thermally induced crack
2. Lack-of-Fusion DOE block
3. Lack-of-Fusion Fatigue Coupon



Geometrically Forced Thermal Crack Coupon



T-blocks with varying thickness (x)

Investigate thick to thin transitions to force thermal cracking

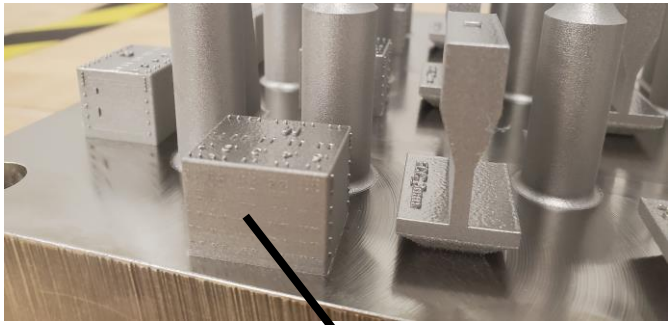
Test Coupon: Direct Print Method

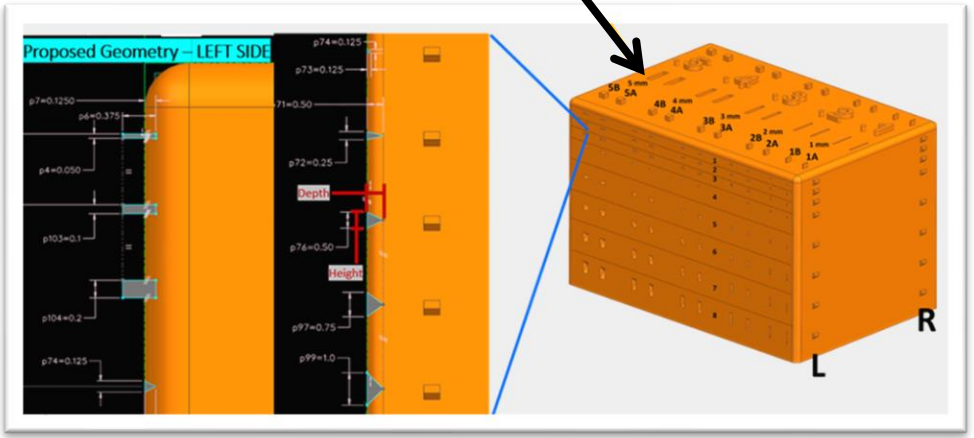
Lack-of-fusion Test Block

Skipping layers while printing creates a lack-of-fusion feature

CAD model dimensions shown. Actual size after printing are smaller due to layer “healing”

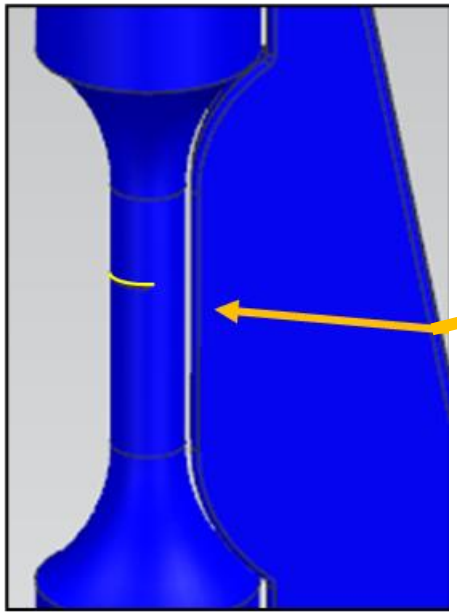
	WIDTH (mm)		0.1	0.2	0.3	0.4	0.5
Shape	HEIGHT (mm)	DEPTH (mm)					
Block	0.05	0.25	R1-1	R1-2	R1-3	R1-4	R1-5
Block	0.1	0.25	R2-1	R2-2	R2-3	R2-4	R2-5
Block	0.2	0.25	R3-1	R3-2	R3-3	R3-4	R3-5
Triangle	0.05	0.25	R4-1	R4-2	R4-3	R4-4	R4-5
Triangle	0.1	0.5	R5-1	R5-2	R5-3	R5-4	R5-5
Triangle	0.15	0.5	R6-1	R6-2	R6-3	R6-4	R6-5
Triangle	0.2	0.5	R7-1	R7-2	R7-3	R7-4	R7-5
Triangle	0.25	0.5	R8-1	R8-2	R8-3	R8-4	R8-5

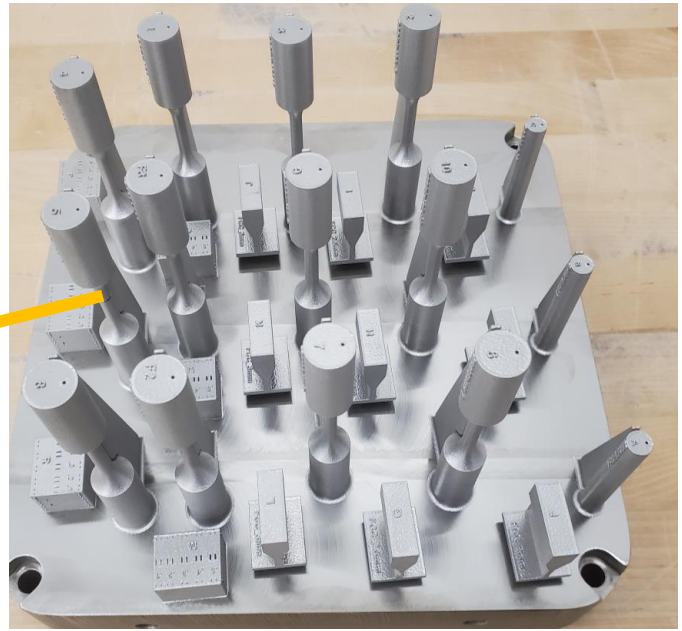


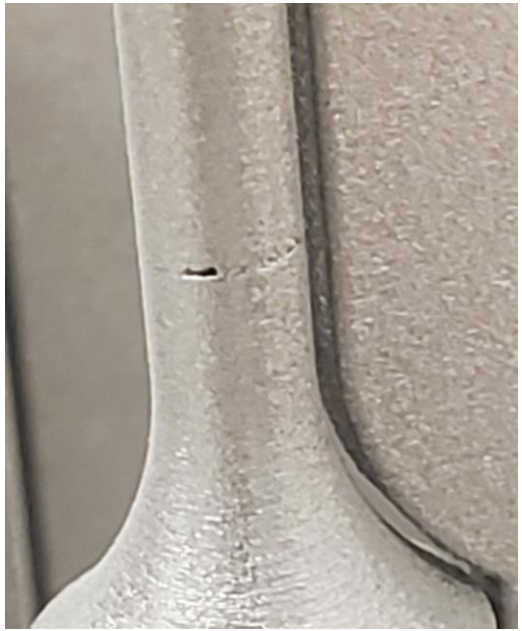


Test Coupon: Direct Print Method

Lack-of-fusion Fatigue Coupon





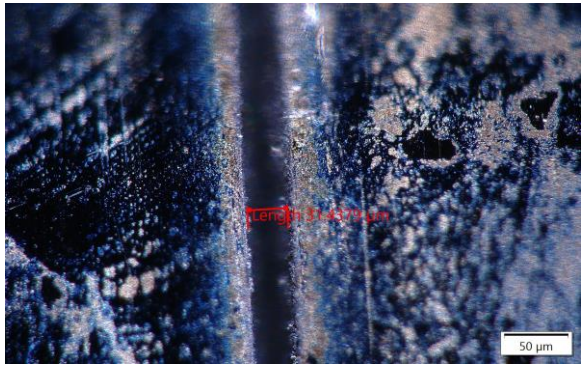


Test Coupon: Post Process Machining Method

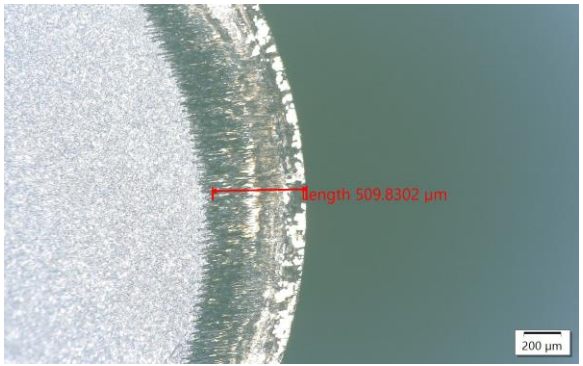
Femtosecond laser machining trials

- Carried out at **Materials Characterization Services**
- These are trial cuts made on spare tool steel of the same diameter (0.2 inch).
- Specimens were then cut at the notch to inspect the depth and length machined.
- Cobalt Chrome specimens have been cut

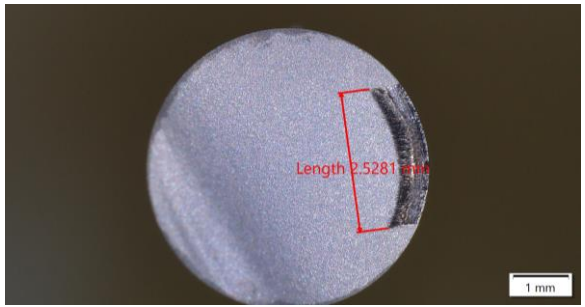
Cut height = 31.44 um (0.0012”)



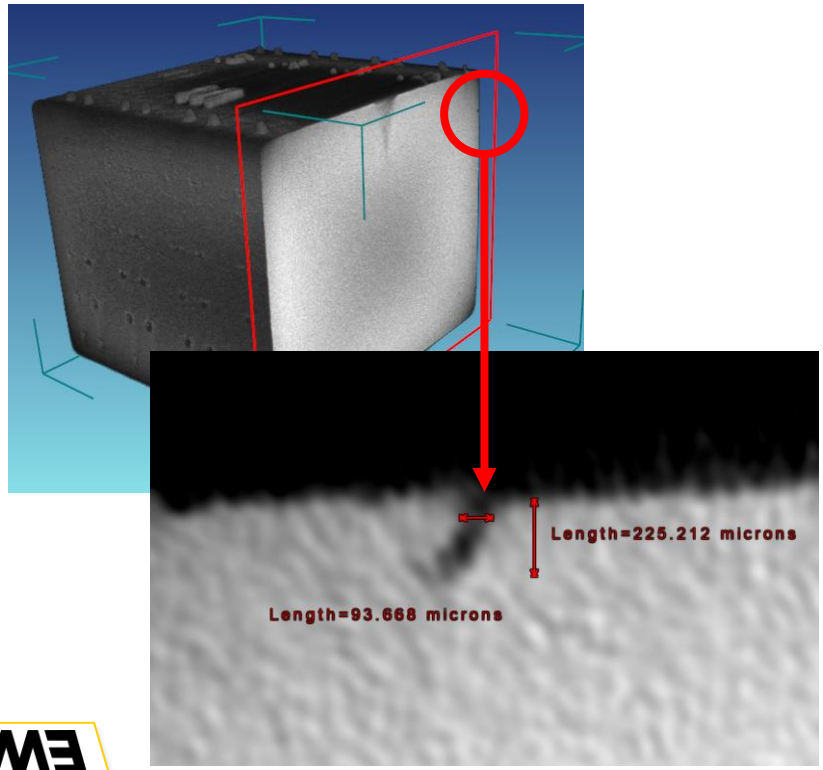
Cut depth = 509.83 um (0.0201”)

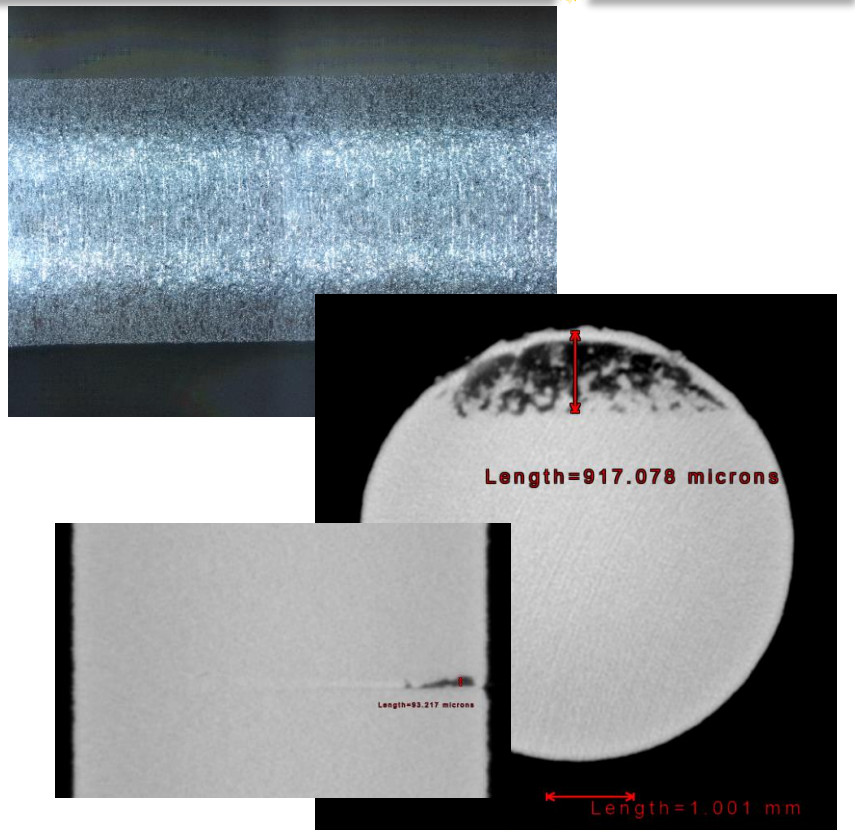


Cut width = 2.5281 mm (0.1”)



Lack-of-fusion Fatigue Coupons



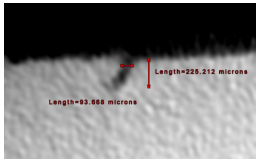


Inspection: Interpretable Flaw

Not Interpretable

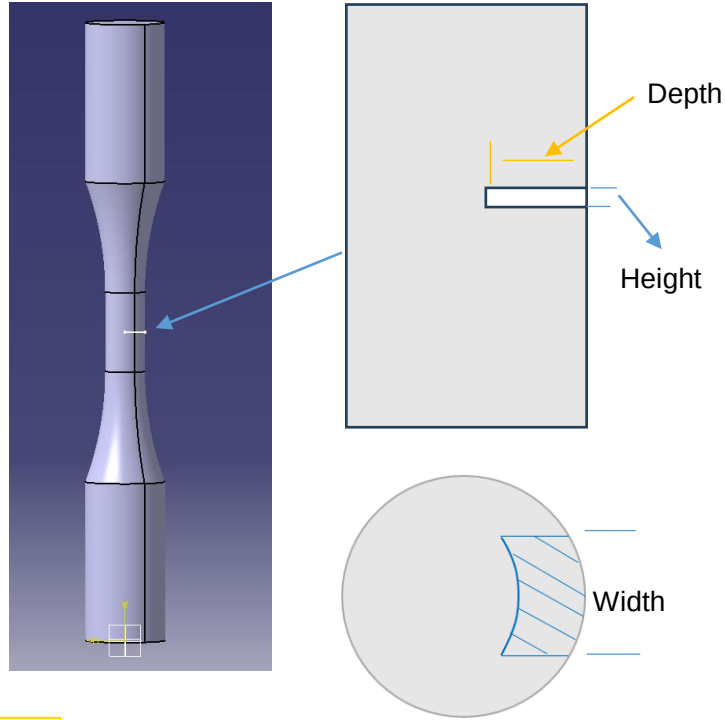
Interpretable

Smallest Interpretable Flaw = 0.2h x 0.25w x 0.2w (mm)



LABELS				1A			1B			2A			2B			3A			3B			4A			4B			5A			5B		
		WIDTH (mm)		0.1			0.1			0.2			0.2			0.3			0.3			0.4			0.4			0.5			0.5		
	HEIGHT (mm)	DEPTH (mm)	Shape								HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)		HEIGHT (mm)	DEPTH (mm)
R1	0.05	0.25	Block	R1-1A			R1-1B			R1-2A			R1-2B			R1-3A			R1-3B			R1-4A			R1-4B			R1-5A			R1-5B		
R2	0.1	0.25	Block	R2-1A			R2-1B			R2-2A			R2-2B			R2-3A			R2-3B			R2-4A			R2-4B			R2-5A			R2-5B		
R3	0.2	0.25	Block	R3-1A			R3-1B			R3-2A	0.077	0.222	R3-2B	0.059	0.219	R3-3A	0.113	0.254	R3-3B	0.095	0.221	R3-4A	0.150	0.254	R3-4B	0.161	0.333	R3-5A	0.129	0.246	R3-5B	0.163	0.246
R4	0.05	0.25	Triangle	R4-1A			R4-1B			R4-2A			R4-2B			R4-3A			R4-3B	0.069	0.176	R4-4A			R4-4B			R4-5A			R4-5B		
R5	0.1	0.5	Triangle	R5-1A			R5-1B			R5-2A			R5-2B			R5-3A			R5-3B			R5-4A			R5-4B			R5-5A			R5-5B		
R6	0.15	0.5	Triangle	R6-1A			R6-1B			R6-2A			R6-2B	0.049	0.102	R6-3A			R6-3B	0.089	0.108	R6-4A	0.071	0.083	R6-4B	0.082	0.061	R6-5A	0.140	0.059	R6-5B	0.128	0.085
R7	0.2	0.5	Triangle	R7-1A			R7-1B			R7-2A			R7-2B			R7-3A	0.066	0.193	R7-3B	0.060	0.227	R7-4A	0.000	0.000	R7-4B	0.000	0.328	R7-5A	0.137	0.143	R7-5B	0.158	0.187
R8	0.25	0.5	Triangle	R8-1A			R8-1B			R8-2A	0.101	0.260	R8-2B	0.075	0.231	R8-3A	0.161	0.277	R8-3B	0.186	0.202	R8-4A	0.115	0.246	R8-4B	0.174	0.269	R8-5A	0.155	0.186	R8-5B	0.263	0.193

Poof of Concept Build #2 Plan



- Build #2 will help further verify repeatability of LOF notch.
- These specimen will be used for preliminary fatigue testing.

Orientation	Condition	Height (H), mm	Depth (D), mm	Width (w), mm	Number of specimens
ZX	LOF notch	0.1	0.25	1	4
	LOF notch	0.1	0.5	1	4
	LOF notch	0.1	1	1	4
	LOF notch	0.2	0.5	1	4
	LOF notch	0.2	0.75	1	4
	LOF notch	0.2	1	1	4
	AS-fabricated	n/a	n/a	n/a	4

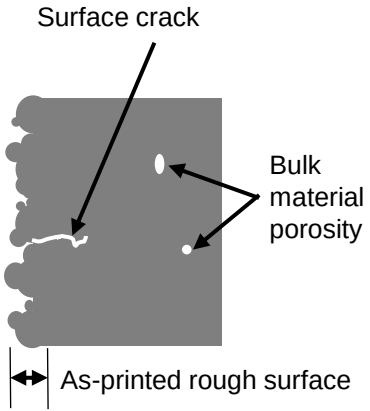
Total	28

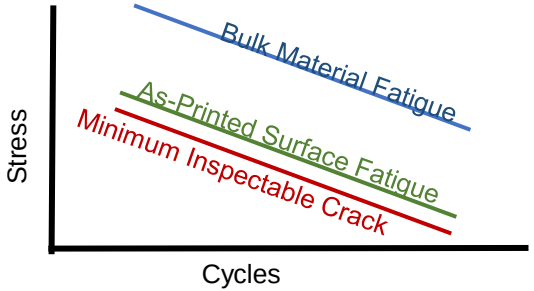
Smallest detected flaw on LOF cubes and fatigue specimens based on CT data were designed/modeled with dimensions of:

- Depth: 0.25 mm (0.0098 inch)
- Height: 0.1 mm (0.004 inch)

Next steps

- *Colibrium* to **fabricate 2nd build** with proposed (LOF) flaw sizes.
  - *NIAR* to CT scan to further verify LOF repeatability.
  - *NIAR* to run **fatigue testing trials** with specimens from 1st and 2nd build.
- *Colibrium* to build & *NIAR* to run **final fatigue testing** w/ min inspectable flaw size
  - (LOF & laser cut vs. as-printed)
- *NIAR* to propose qualification approach for as-printed surfaces





Questions?