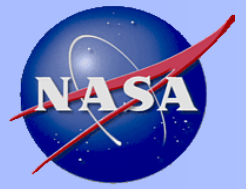

Flash Thermal Diffusivity Measurements and Inspection of Additively Manufactured Ti-6Al-4V Specimens with Varying Process Parameters

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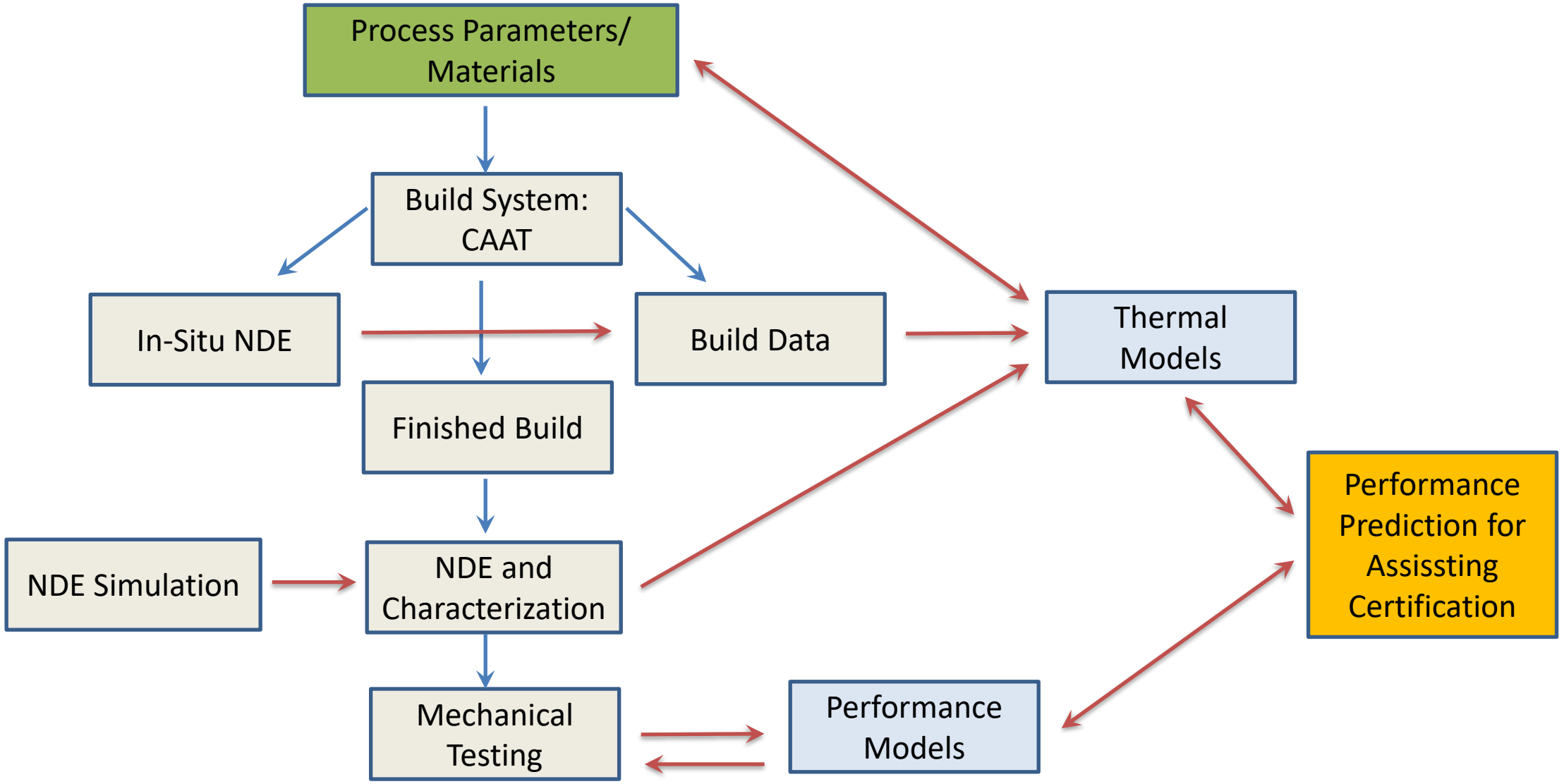
SPIE Thermosense Conference April 30 – May 4, 2023

Outline

- Introduction/Motivation
- Laser Powder Bed Fusion Additive Manufacturing
  - Description of Configurable Architecture Additive Testbed (CAAT)
  - Disk Samples Built with Varying Process Parameters
  - Thermal Inspection Systems
- Thermal Inspection Results
  - Through Transmission Diffusivity Measurements with Comparison to X-ray CT and Ultrasonics
  - Single Side Thermal Inspection with Comparison to X-ray CT
- Conclusions

NASA Transformational Tools and Technologies Project – Additive Manufacturing (Metals)

Nondestructive Evaluation Sciences Branch



Introduction

Objectives

• Develop nondestructive evaluation (NDE) techniques to inspect additively manufactured metal parts.

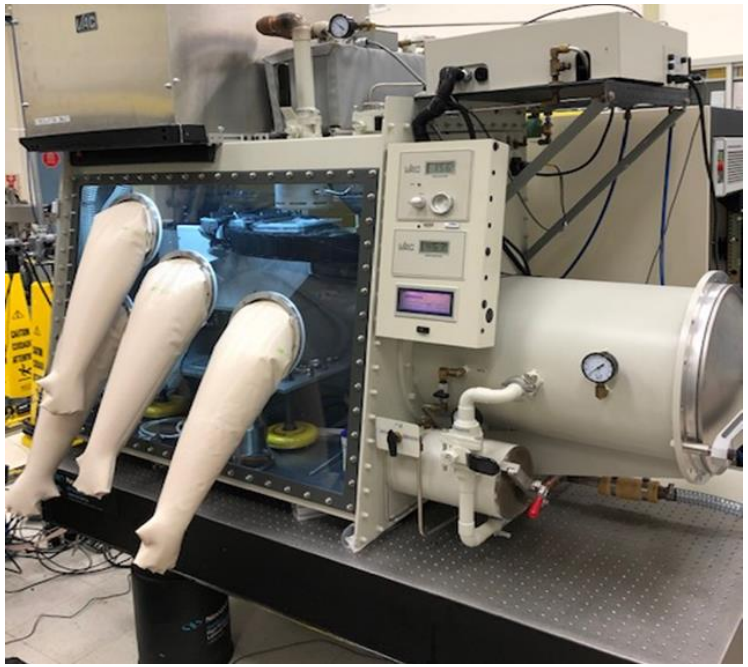
• Investigate thermal NDE as an inspection technique for built parts and for in-situ inspections during the build.

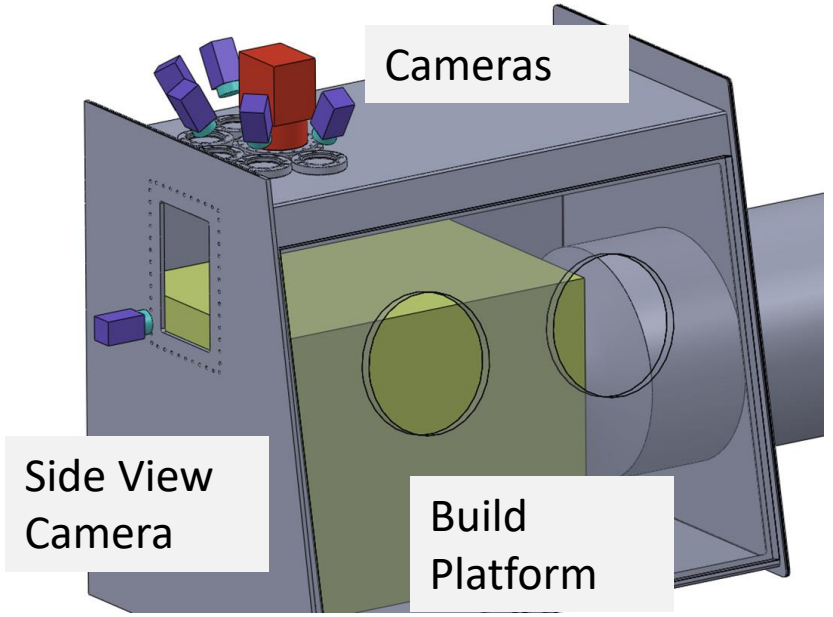
• Validate the thermal inspection results with other NDE techniques such as X-ray CT and ultrasound.

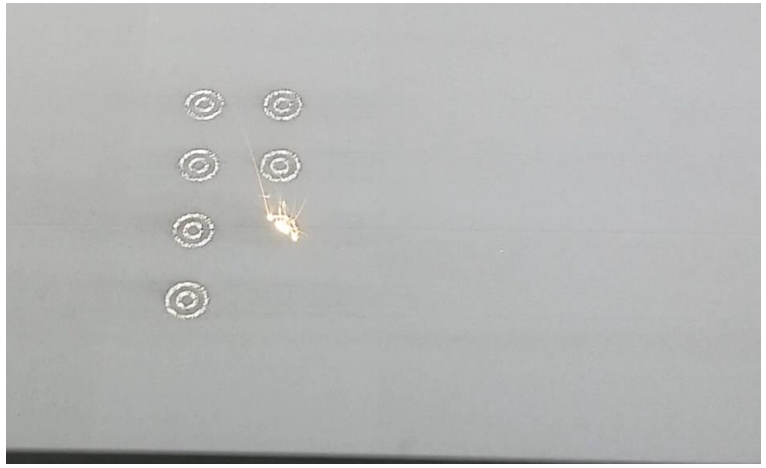
Payoffs

• Additively manufactured parts must be certified for broad application onto aircraft structures and NDE techniques are required to ensure part quality.

Configurable Architecture Additive Testbed (CAAT)

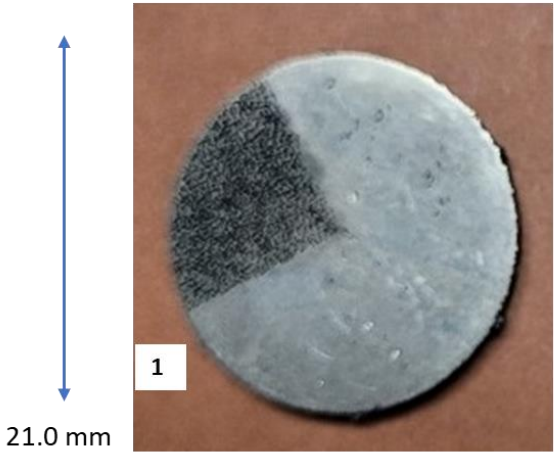


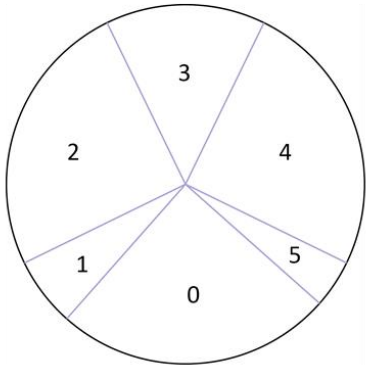




Samples Manufactured with the CAAT

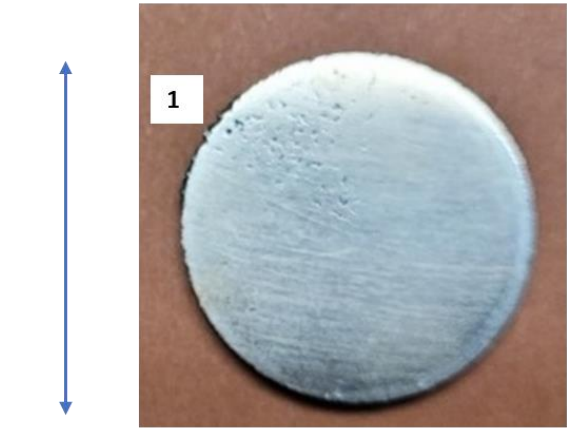
Disk: A Polished

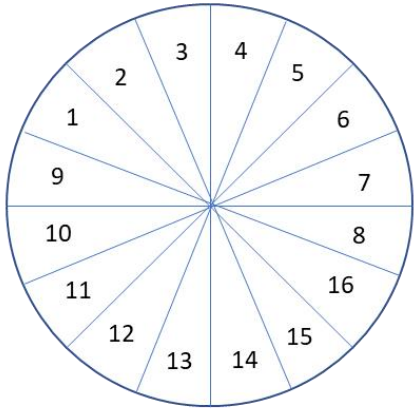




Zone (n)	Power (watts)	Velocity (mm/sec)	Shape / angular zone [radians]
0	345	1176	Pi/2
1	345	1176	Pi/8
2	137	1176	Pi/2
3	345	1176	Pi/4
4	345	1176	Pi/2
5	345	1176	Pi/8

Disk: B Polished

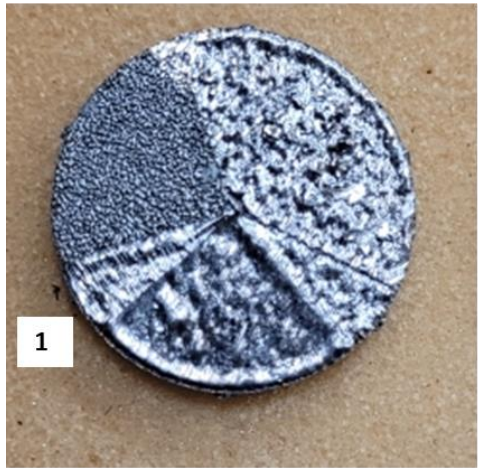




Zone (n)	Power (watts)	Velocity (mm/sed)	Shape / angular zone [radians]
1	221	1176	Pi/8
2	221	1092	Pi/8
3	221	1008	Pi/8
4	221	924	Pi/8
5	221	840	Pi/8
6	221	756	Pi/8
7	221	672	Pi/8
8	221	588	Pi/8
9	308	1175	Pi/8
10	308	1092	Pi/8
11	308	1008	Pi/8
12	308	924	Pi/8
13	308	840	Pi/8
14	308	756	Pi/8
15	308	672	Pi/8
16	308	588	Pi/8

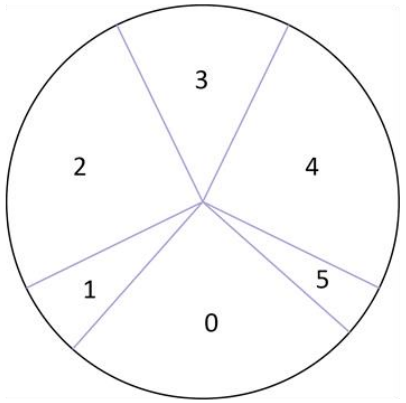
Samples Manufactured with the CAAT

Disk: C Unpainted and Unpolished



21.0 mm

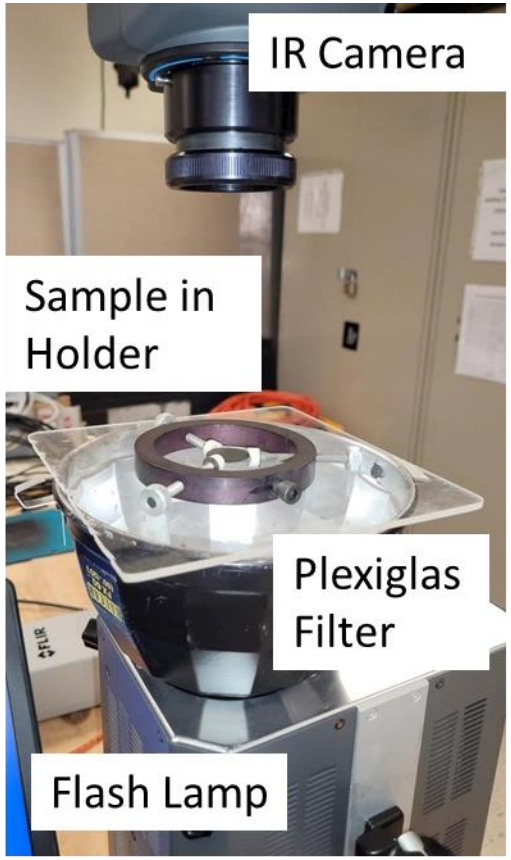
Disk: D Unpainted and Unpolished



Zone (n)	Power (watts)	Velocity (mm/sec)	Shape / angular zone [radians]
0	345	672	Pi/2
1	345	1176	Pi/8
2	137	1176	Pi/2
3	345	1176	Pi/4
4	345	1176	Pi/2
5	345	1176	Pi/8

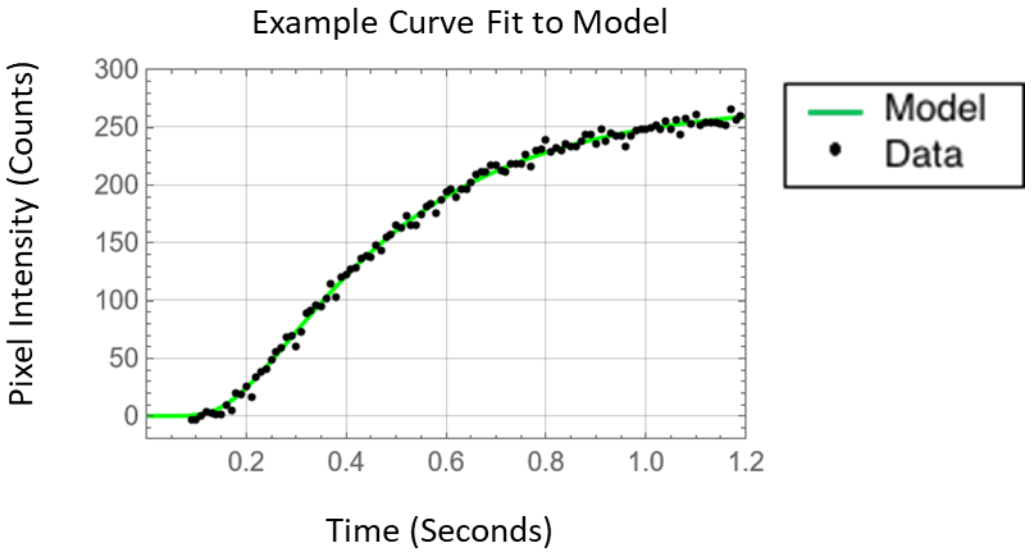
Through Transmission Thermal Inspection System

Through Transmission

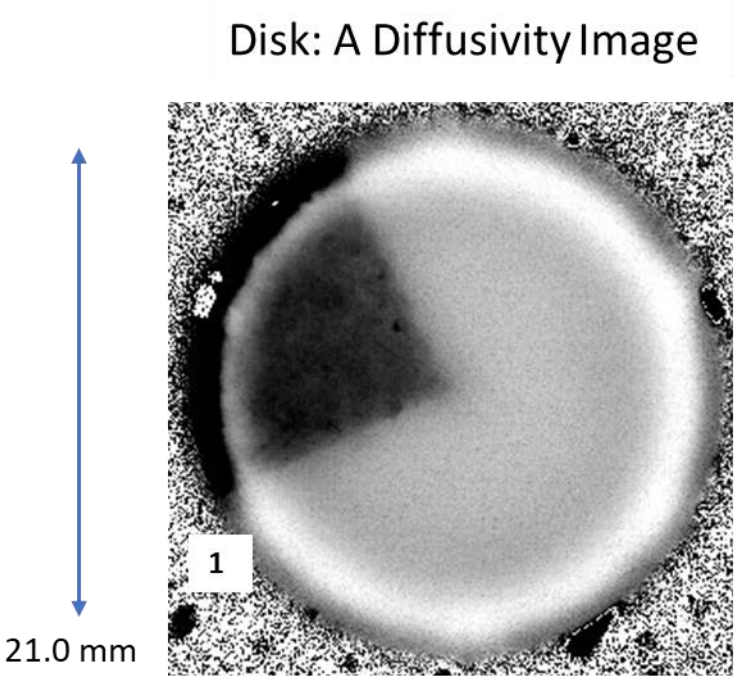


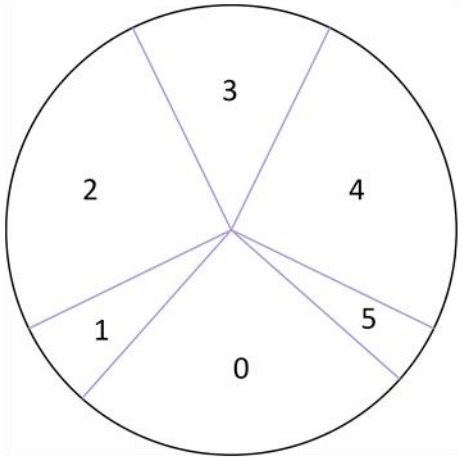
Through Transmission Technique

$$T(t) = \begin{cases} 2\,T_{max}\sqrt{\dfrac{l^2}{\pi\,\alpha\,t}}\left(e^{-\frac{l^2}{4\,\alpha\,t}} + e^{-\frac{9l^2}{4\,\alpha\,t}}\right), t < 0.4\,\dfrac{l^2}{\alpha} \\ 2\,T_{max}\left(1 - e^{-\frac{\alpha\,t\,\pi^2}{l^2}}\right), t \geq 0.4\,\dfrac{l^2}{\alpha} \end{cases}$$



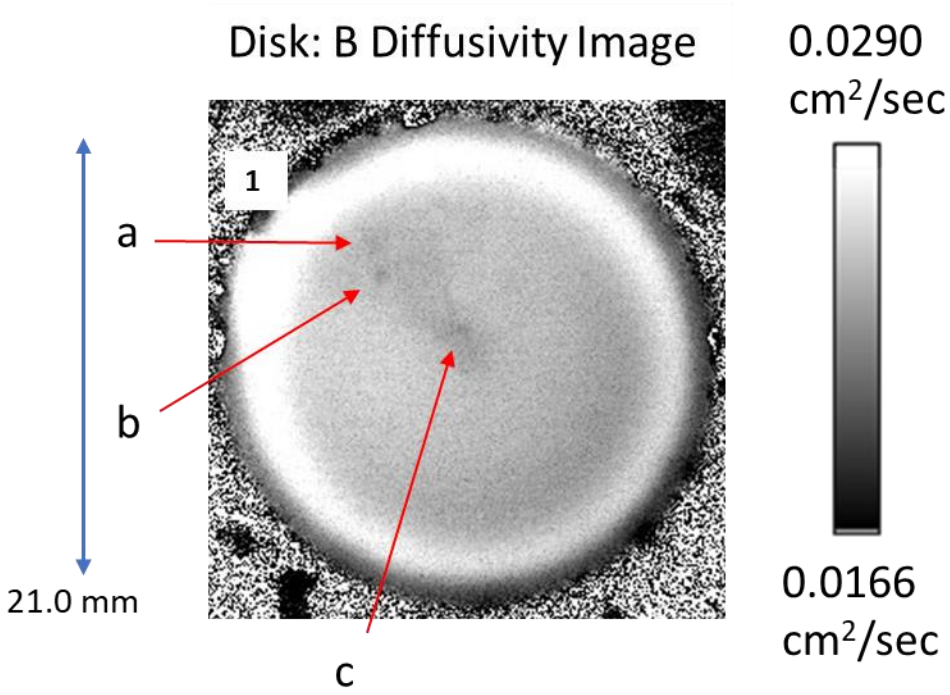
Through Transmission Thermal Results

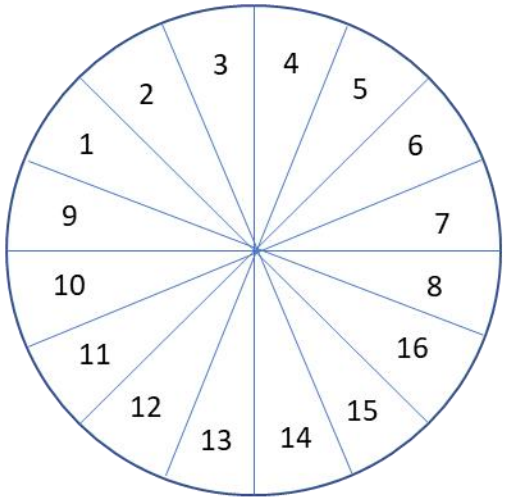




Zone (n)	Power (watts)	Velocity (mm/sec)	Shape / angular zone [radians]	Thermal Diffusivity (cm^2/sec)
0	345	1176	Pi/2	0.0258 +/-0.00043
1	345	1176	Pi/8	0.0253 +/-0.00036
2	137	1176	Pi/2	0.0186+/-0.00031
3	345	1176	Pi/4	0.0256 +/-0.00040
4	345	1176	Pi/2	0.0258 +/-0.00038
5	345	1176	Pi/8	0.0257 +/-0.00050

Through Transmission Thermal Results



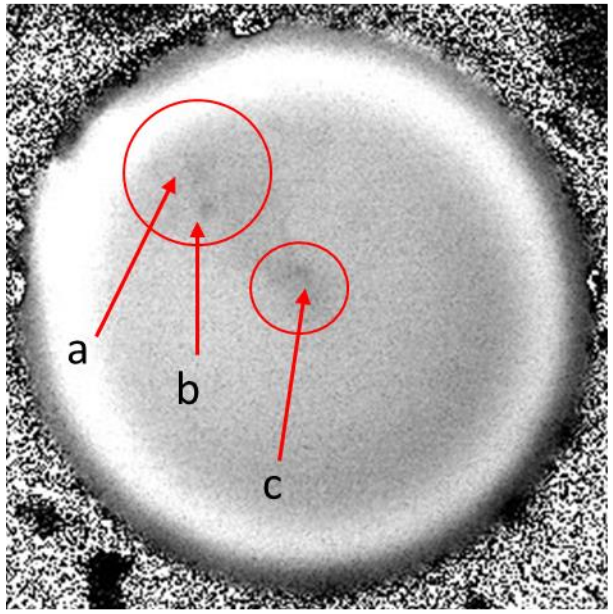


Zone (n)	Power (watts)	Velocity (mm/sec)	Shape / angular zone [radians]	Thermal Diffusivity (cm^2/sec)
1	221	1176	Pi/8	0.0256 +/-0.00052
2	221	1092	Pi/8	0.0253 +/-0.00055
3	221	1008	Pi/8	0.0257 +/-0.00055
4	221	924	Pi/8	0.0258 +/-0.00061
5	221	840	Pi/8	0.0258 +/-0.00054
6	221	756	Pi/8	0.0257 +/-0.00048
7	221	672	Pi/8	0.0256 +/-0.00046
8	221	588	Pi/8	0.0253 +/-0.00055
9	308	1175	Pi/8	0.0267 +/-0.00052
10	308	1092	Pi/8	0.0267 +/-0.00052
11	308	1008	Pi/8	0.0264 +/-0.00052
12	308	924	Pi/8	0.0261 +/-0.00054
13	308	840	Pi/8	0.0257 +/- 0.00054
14	308	756	Pi/8	0.0257 +/-0.00051
15	308	672	Pi/8	0.0254 +/-0.00053
16	308	588	Pi/8	0.0252 +/-0.00052

a = 0.0250 +/- 0.00052, b = 0.0247 +/- 0.00066,
c = 0.0241 +/-0.0006 cm^2/sec

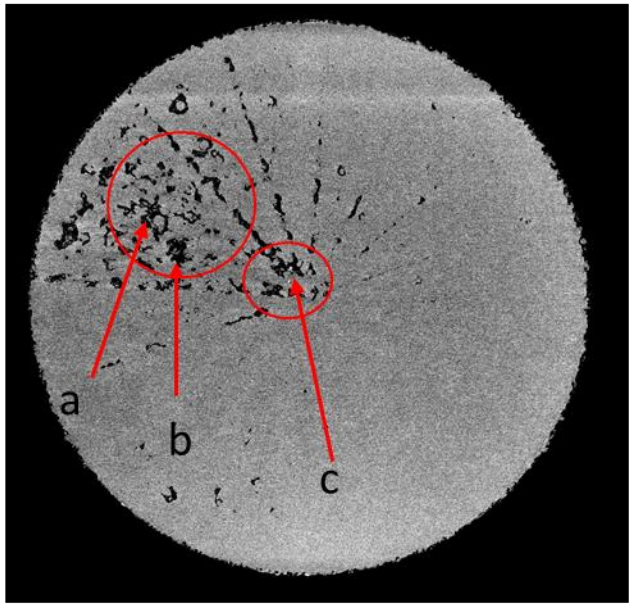
Through Transmission Thermal Results Compared to X-ray CT

Disk: B Diffusivity Image

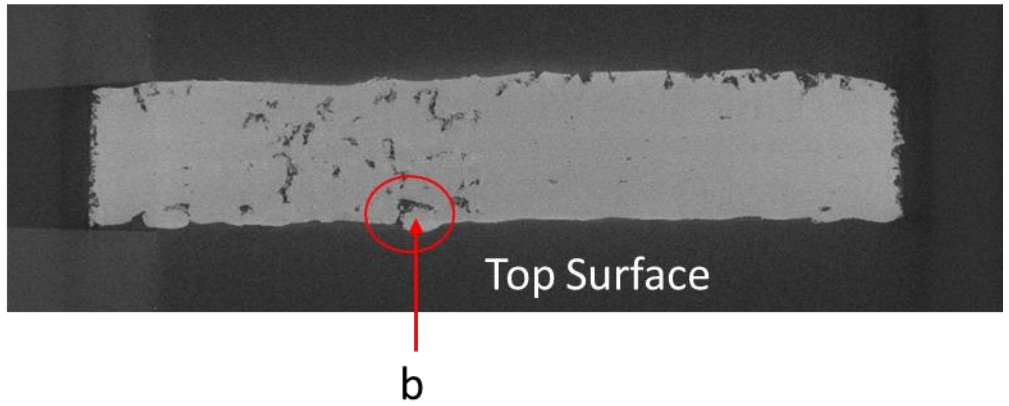


21.0 mm

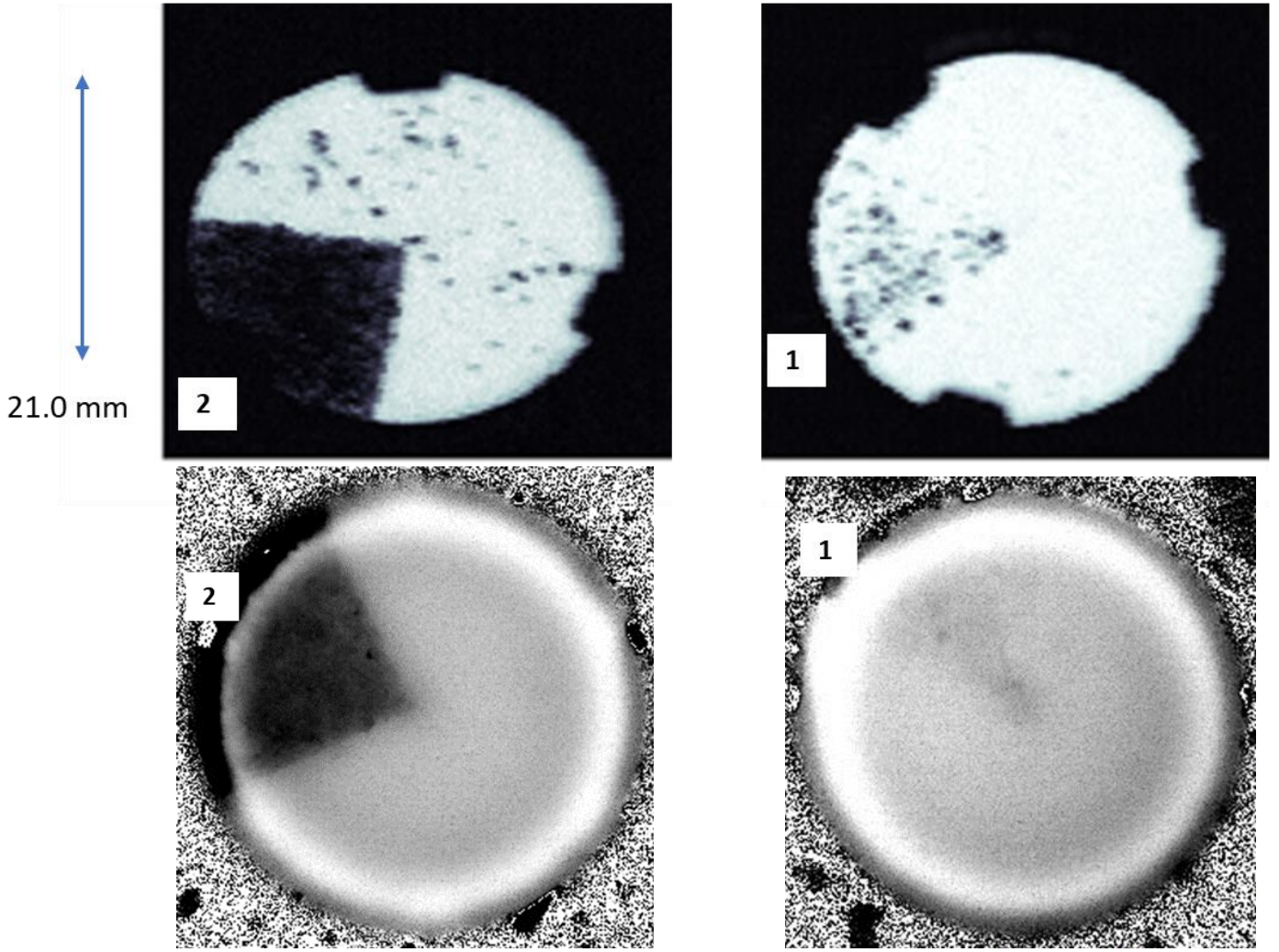
Disk: B X-ray CT
Transverse Slice Image



Disk B: X-ray CT Vertical Slice Image
for defect b.

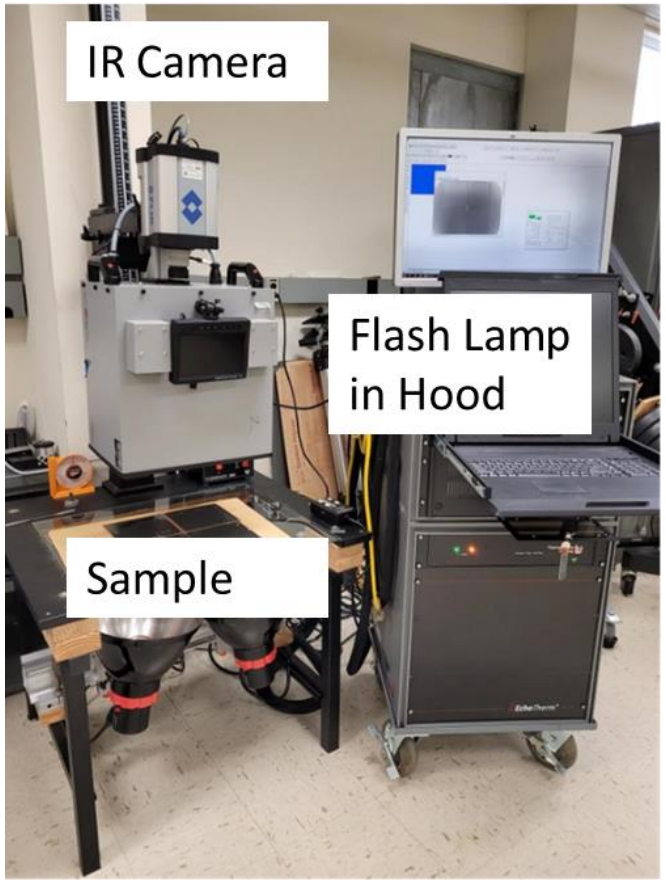


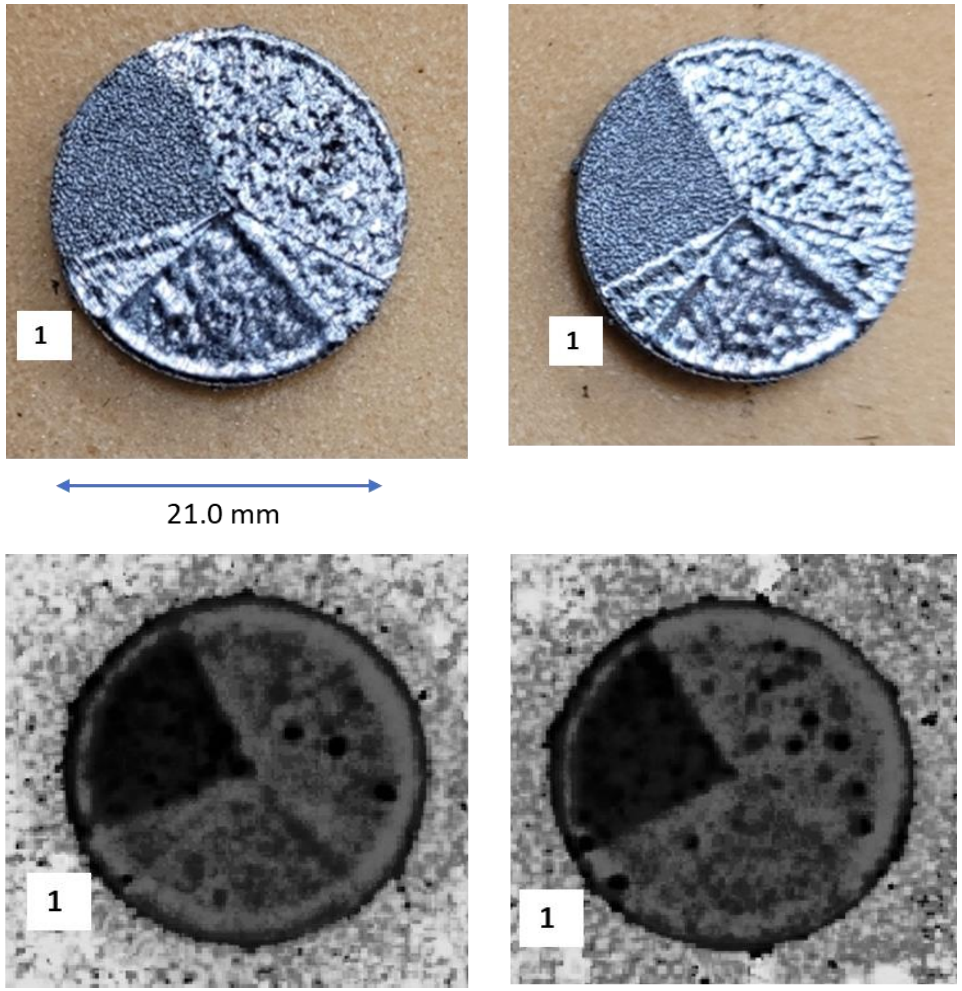
Through Transmission Thermal Results Compared to Ultrasound



Single Side Thermal Inspection Results

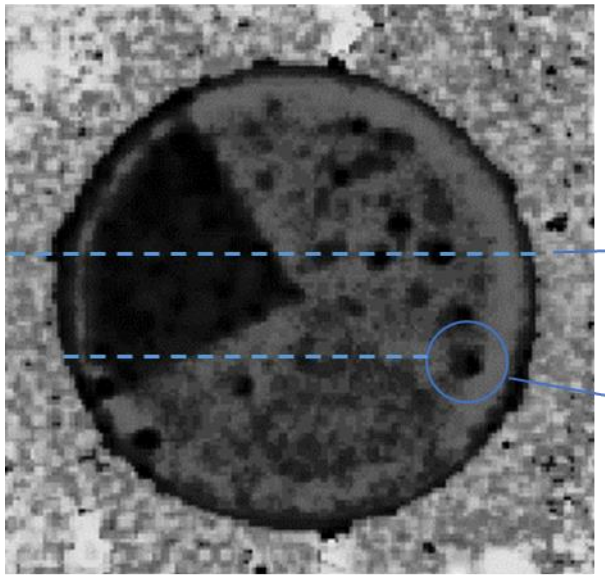
Single Side Setup

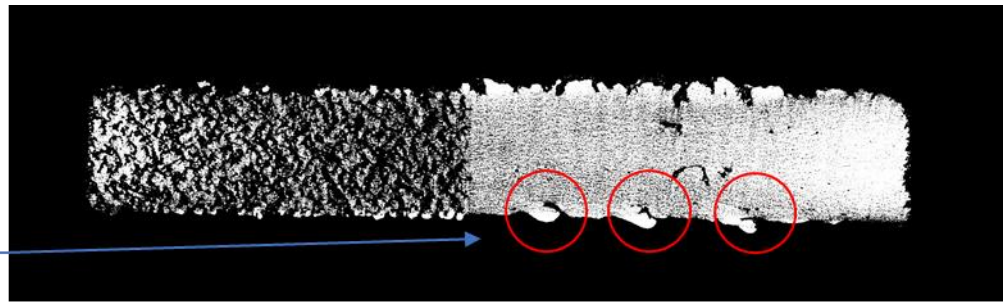


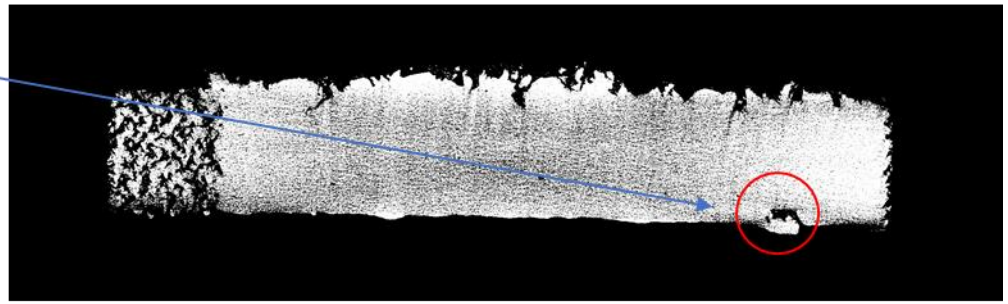


Principal Component Analysis (PCA) Processed Inspection Images

Single Side Thermal Inspection Results Compared to X-ray CT







21.0 mm

Conclusions

- Lack of fusion porosity and areas of large porosity were detected with the thermal diffusivity measurements.
- Small changes in the processing parameters were not detectable with changes in the thermal diffusivity.
- Single sided thermal inspections detected near surface voids on unpainted and rough surface samples and this inspection can be implemented in-situ with thermal inspections performed during the build.
- Data fusion between processing parameters and NDE results will require registration with goal to compile results into a centralized data base.