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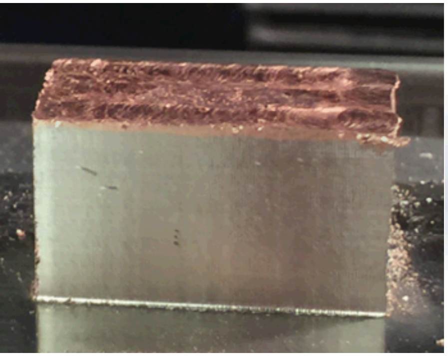

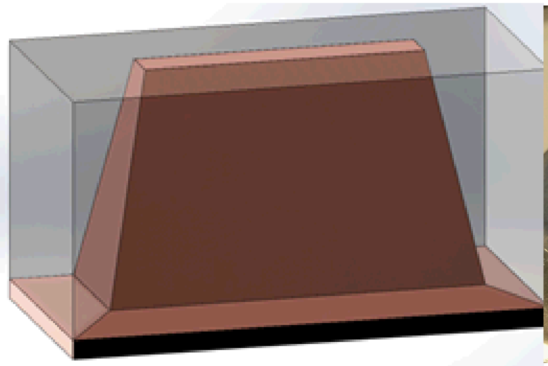

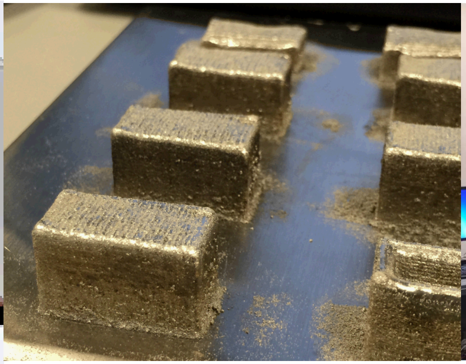

Thermal Concentrator Design Enabled by Multi-Material 3D Metal Printing

Tim Price, D. Keicher, and S. Whetten

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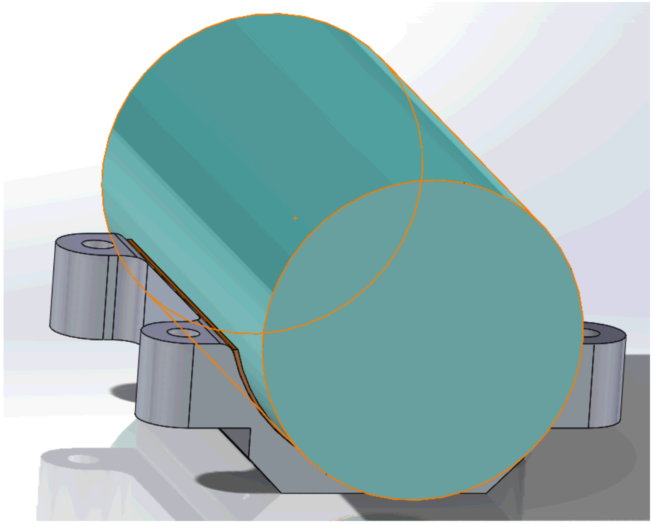
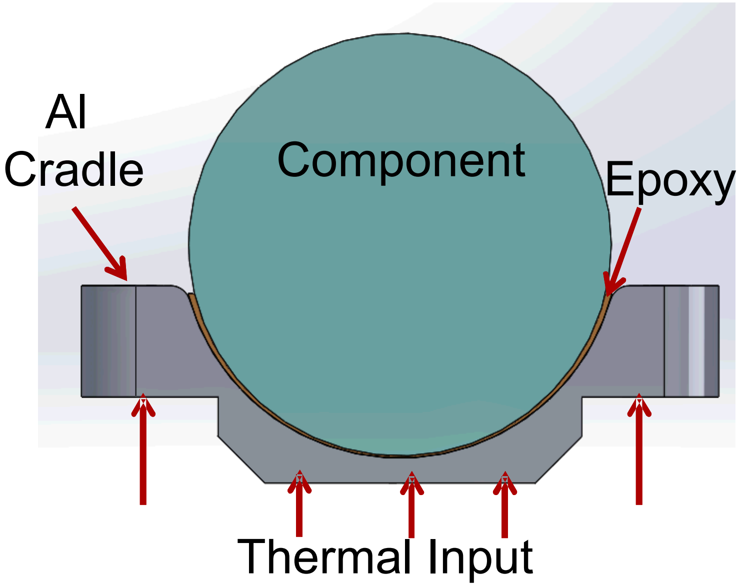
Introduction

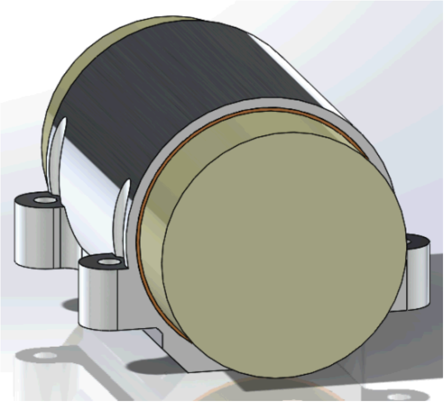
- Objective: Maximize thermal energy transfer into a component
- Existing structures are solid SS or Al, traditional manufacturing
- Multi-material AM is appealing as a process and design enabler

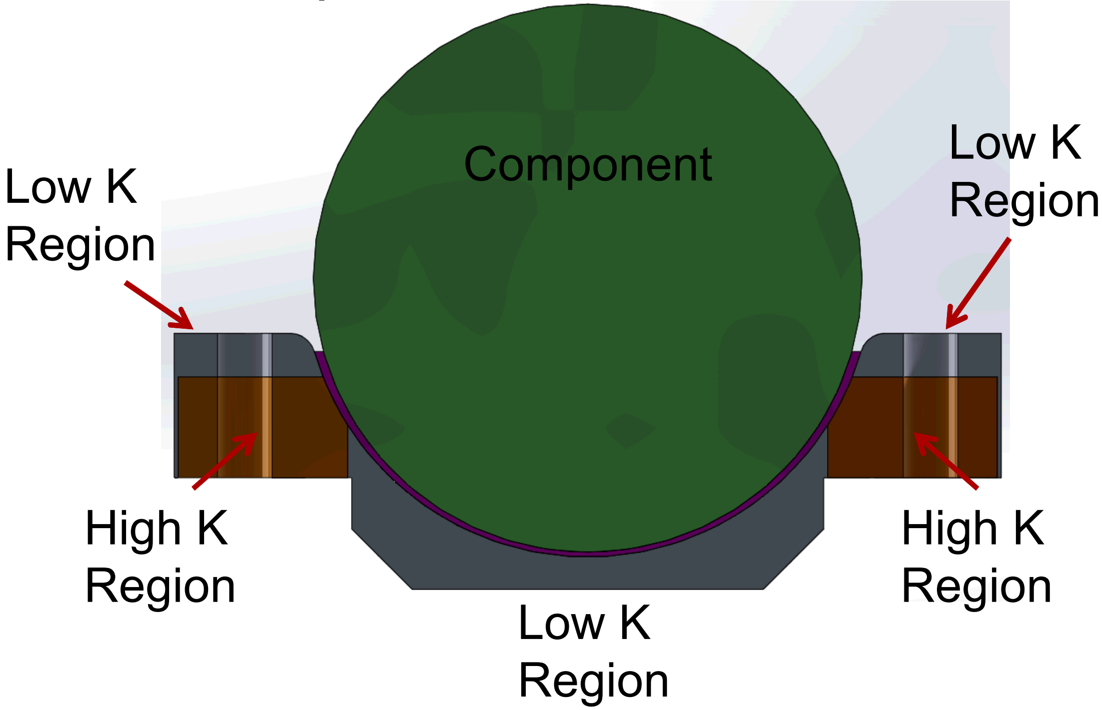


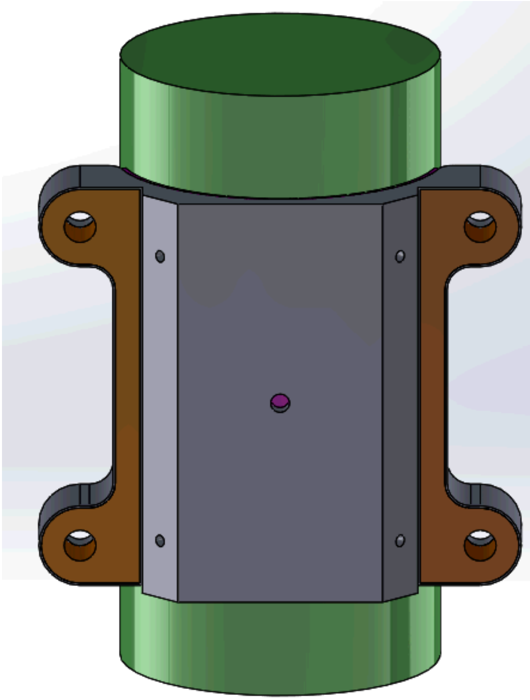


Concept Design

- Need to create large ΔT while maintaining structural strength
- Design Cradle – High conductivity (K) regions surrounded by low K to direct energy to area of interest to concentrate heat input.

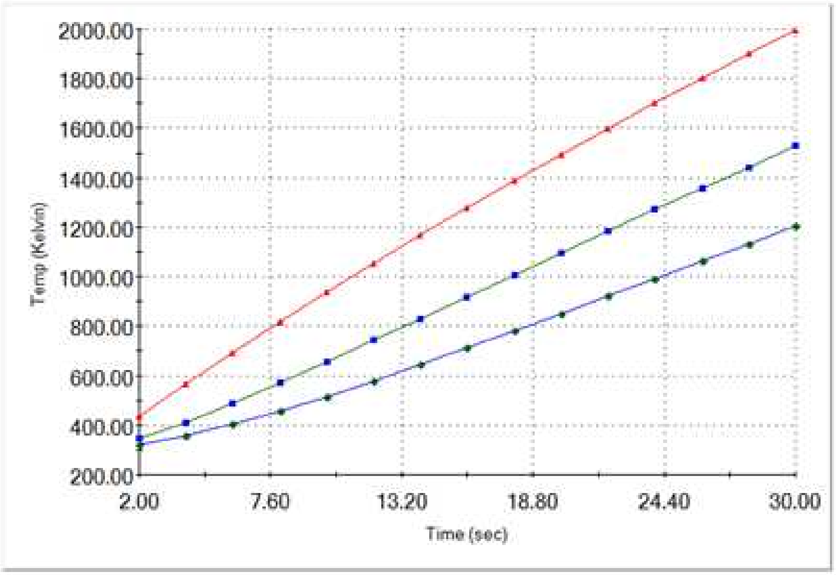






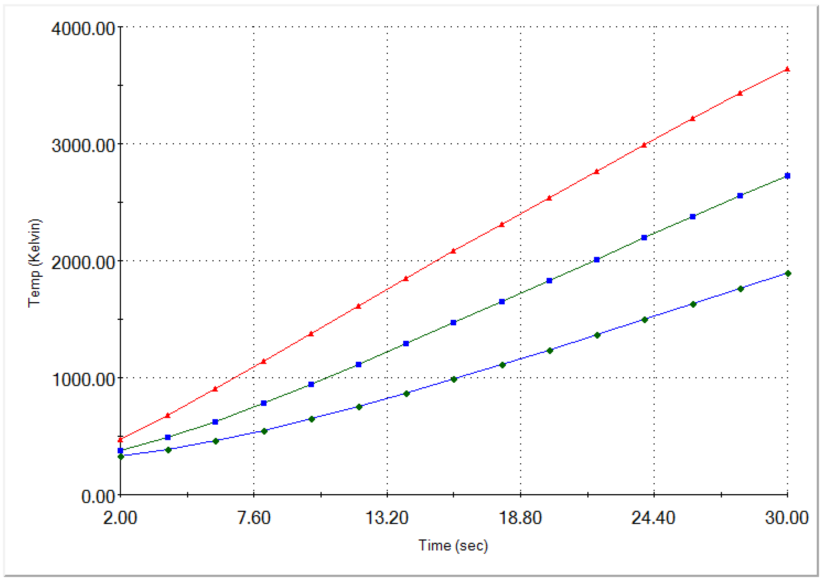
Transient Temperature Results
Traditional Assembly vs. Concentrator

Traditional Cradle



Predicted transient temperature response in *traditional cradle* assembly at points within the component.

Thermal Concentration Cradle



Predicted transient temperature response in *concentrating cradle* assembly at points within the component.

Project Tasks

1. High thermal conductivity metal
   a) Identify material source
   b) Develop LENS process conditions to optimize printing of high thermal conductivity metal
2. Design
   a) Design MM structures for fabrication
   b) Perform transient thermal analysis of MM and wrought structures
   c) Design test fixtures and apparatus for transient thermal analysis
   d) Procure other materials needed for testing
3. 3D print MM structures
   a) Print MM structures on LENS system
   b) Post process machine MM structures for testing
4. Produce wrought material samples in same shape as MM printed part geometry
5. Characterization and testing
   a) Instrument MM and wrought structures for transient thermal analysis
      i. Thermocouple
      ii. IR video imaging
   b) Test structures to measure response to thermal input
   c) Compare measured results to predicted results
   d) Submit selected sample for cross-sectional analysis for microstructure and defect characterization

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High Thermal Conductivity Metal

- Copper Powder
  - Spherical
  - Mean dia. 86µm
  - 385 W/mK
- Graphite Powder
  - Non-Shperical, Flake
  - 70-625µm
  - 130 W/mK
- Final powder
  - 85 vol.% Cu
  - 15 vol.% C
- Roll mix for 15 minutes

Table 1: Summary of physical properties of the most promising MMCs for electronic applications.

Matrix		Reinforcement Type	Reinforcement Vol %	Density g/cm^3	CTE $10^{-6}/K$	Thermal conductivity W/mK
METALS						
W/Cu	**75/25**		0	15.7	8.5	236
Mo/Cu	**75/25**		0	9.8	9.0	180
Al/Si	**50/50**		0	2.5	11.0	140
W/Ni/Cu	**95/3.5/1.5**		0	18.0	4.5	173
Cu/Invar/Cu			0	8.3	6.5	138(XY); 40(Z)
Cu/Mo/Cu			0	9.8	6.0	210(XY); 170(Z)
COMPOSITES						
C fibre		-	0	1.8	L=4-5, T=-1	100-500
Carbon Nanotubes (SWCNTs)		-	0	2	-1.0	6600
Vapour Grown C Fibres		-	0	1.8-2	-1.0	1950
Carbon		VGCF	70	1.8-2		910
Epoxy		C fibre	60	1.85	-1.1	310 (XY)
Epoxy		VGCF	73	1.87		661
SiC		VGCF	20	2.9		310
Copper		Diamond	50	5.35	5.5	420
Copper		C fibre	28	7.2	6.5	290 (XY)
Copper		CNTs	50	5.45	-	1024
Copper		**VGCNF**	**50**	**5.45**	**5.5**	**840**
Copper		C particles	50	5.9	8-9	150-300
Beryllium		BeO	-	-	6.1	320
Aluminium		VGCF	37	2.44	5	642
Aluminium		C fibre short	40	2.40	4.0	230

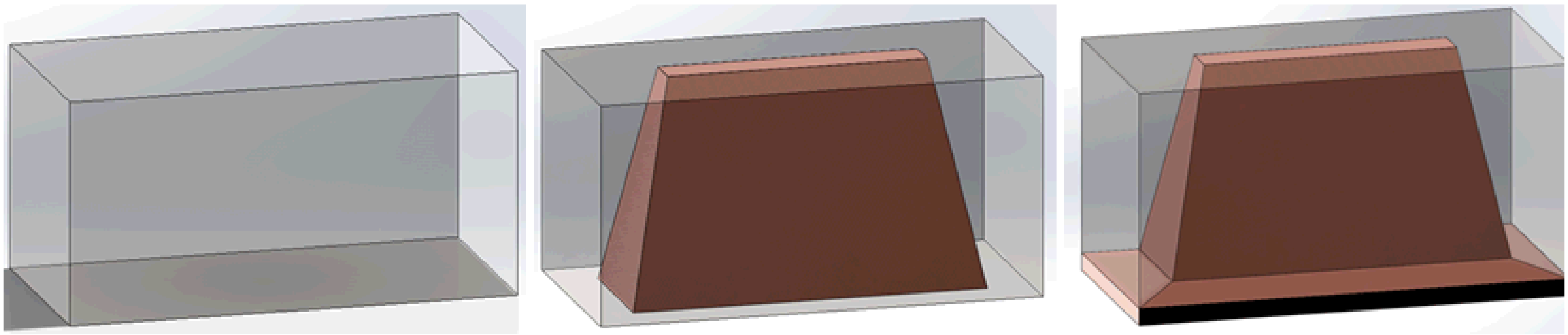
Novel Copper/Carbon Nanofibres Composites for High Thermal Conductivity Electronic Packaging, J. Barcena, J. Maudes, J. Coleto and I. Obieta

High Thermal Conductivity Material

Low Thermal Conductivity Metal

- 304L
  - 45 -105 µm
  - Spherical
  - Thermal Conductivity 16 W/mK

Thermal Concentrator Designs

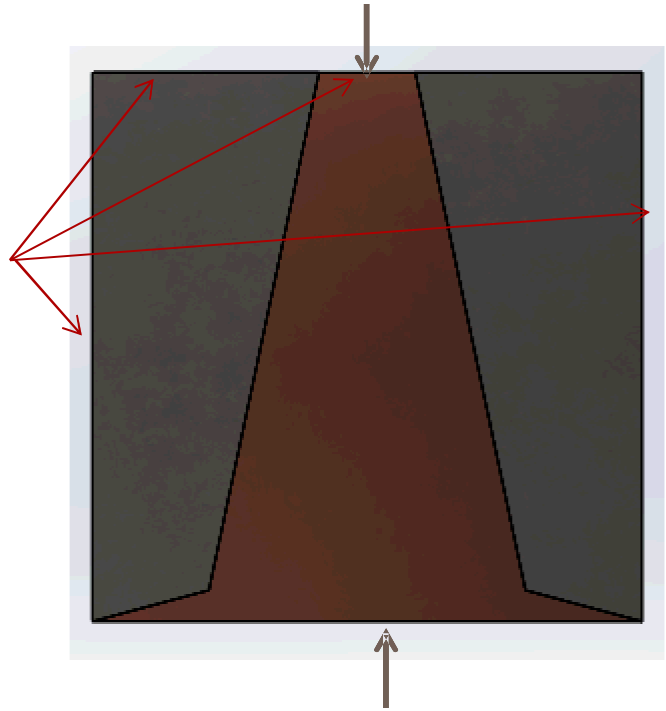


- Test Geometry
  - 0.5” x 1.0” x 0.5” Blocks
    - 304L Stainless Steel
    - Tapered Cu Insert in 304L Stainless Steel Block
    - Tapered Cu Insert in Ti-6Al-4V Block (FEA only)

Transient Thermal FEA

Transient temperature measured at center point on to of test vehicle

Boundary conditions applied to outside surfaces for ambient temperature, convection, and radiation

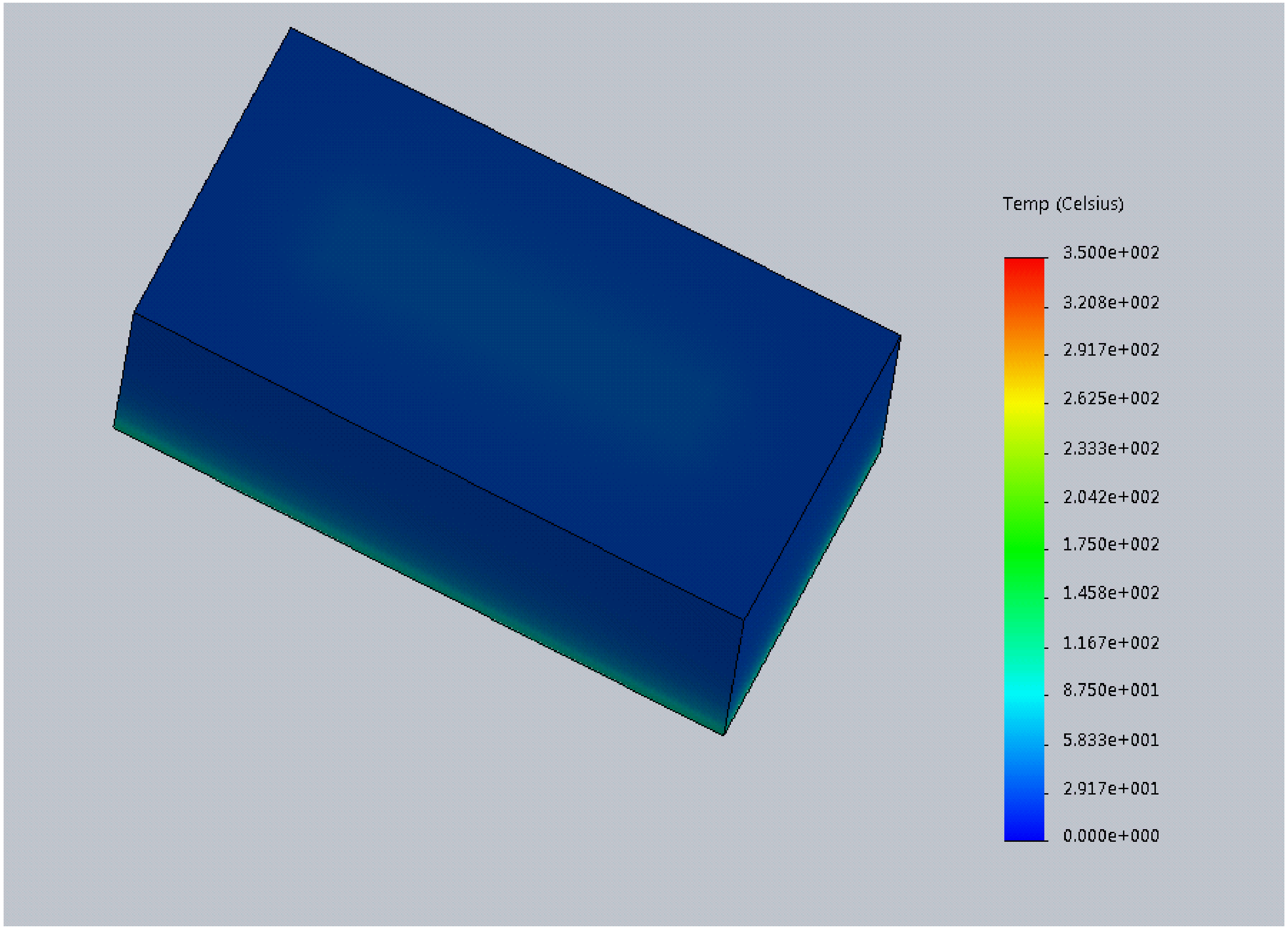


Heat applied to bottom of test vehicle, temperature at base maintained to 350°C

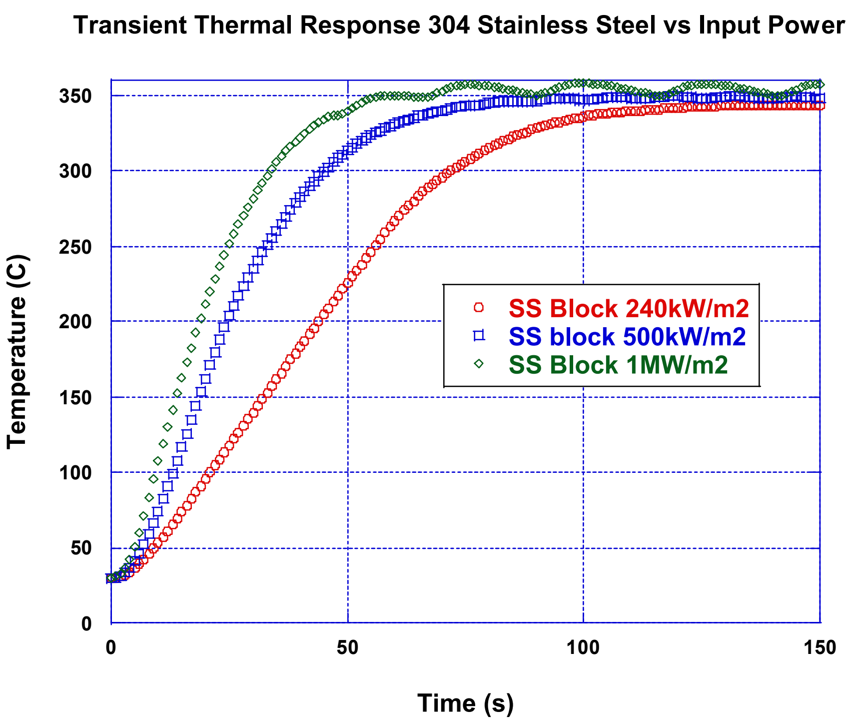
Transient Thermal FEA Setup

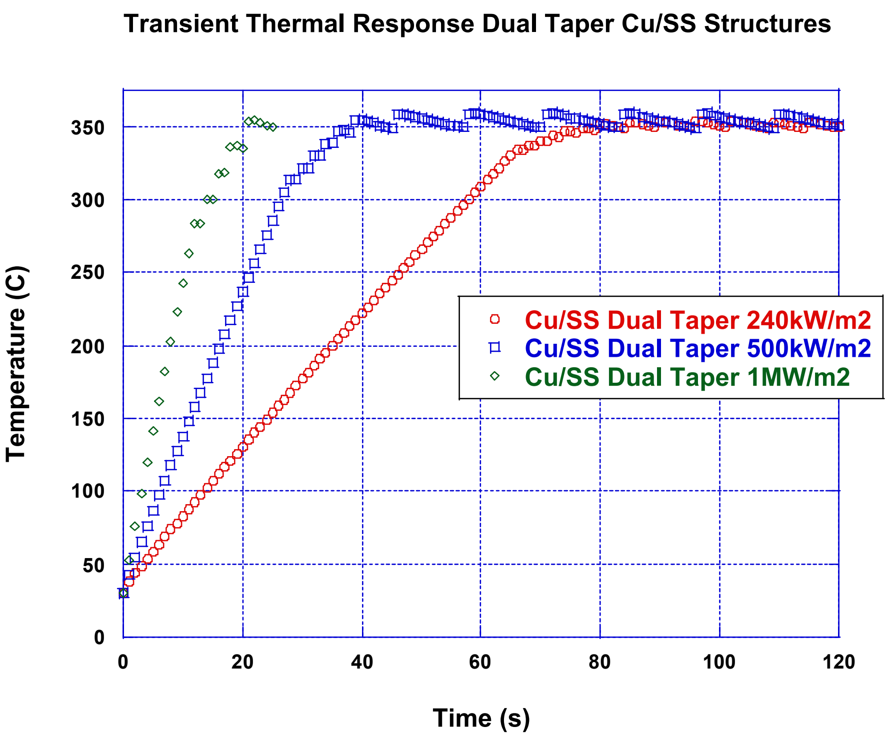
- Heat input at maximum rate of heaters
  - 240,000 W/m^2
- Input face initial temperature 350° C
- Input temperature held at 350° C
- Convection to air 30 W/m^2K
- Ambient temperature 30° C
- Initial Part Temperature 30 ° C

Simulation Results for Single Taper Cu

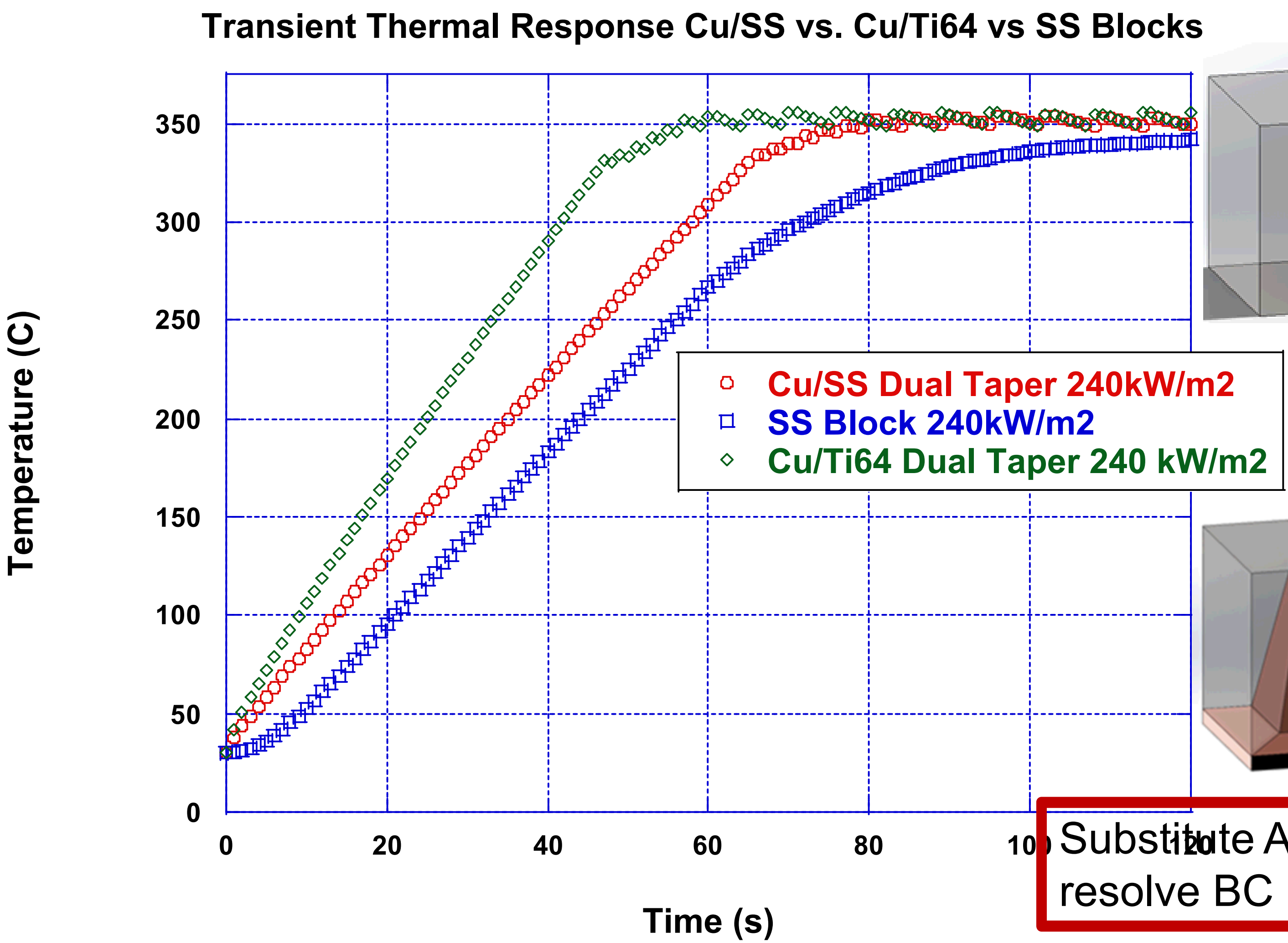


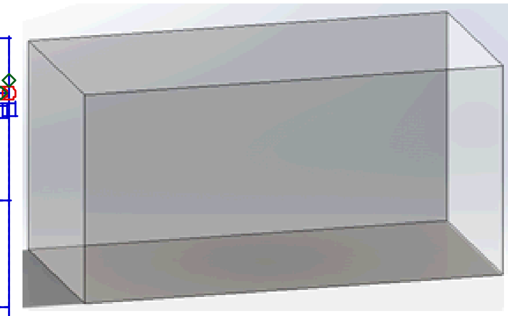
Simulated Transient Thermal Response

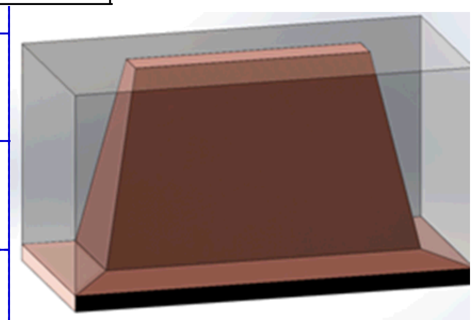




Simulated Transient Thermal Response



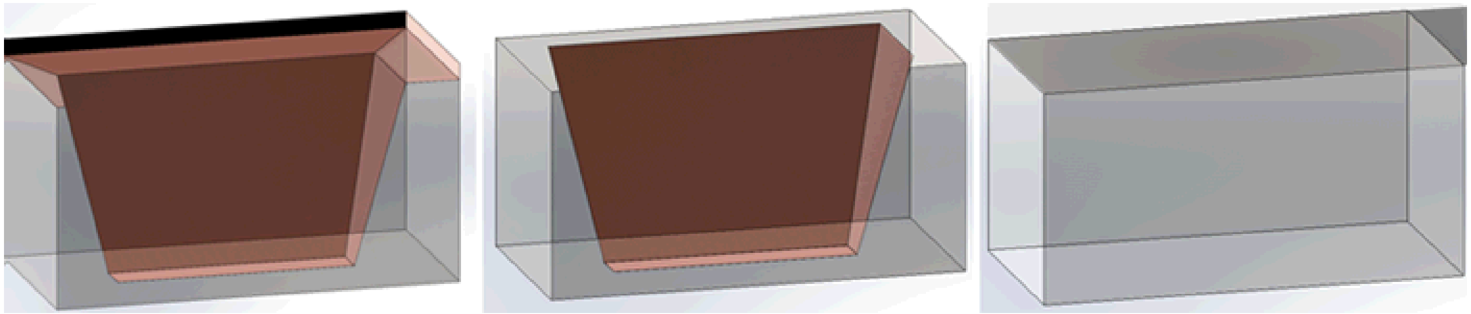




Substitute ANSYS plots, resolve BC ringing

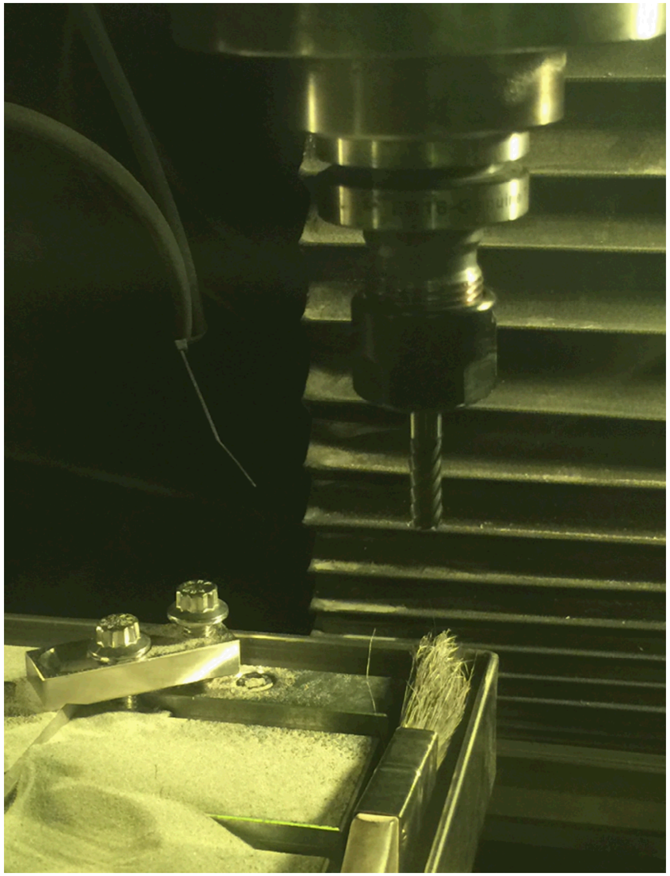
LENS Machine

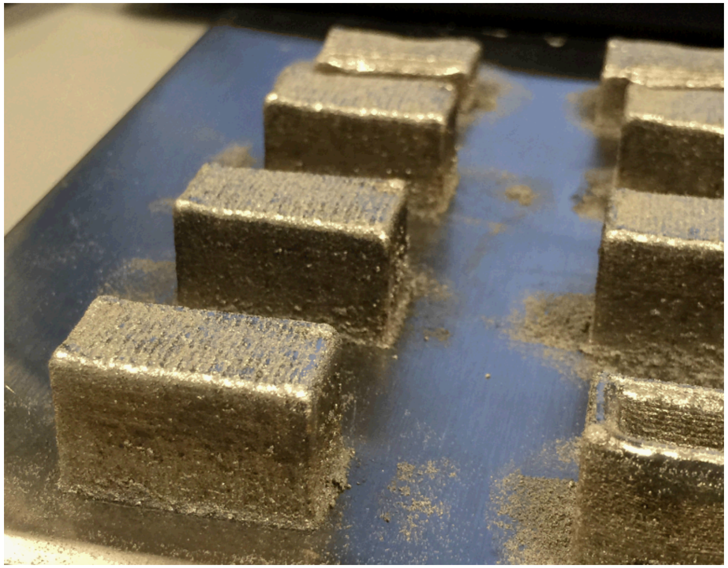
SS – Cu C Multi-Material

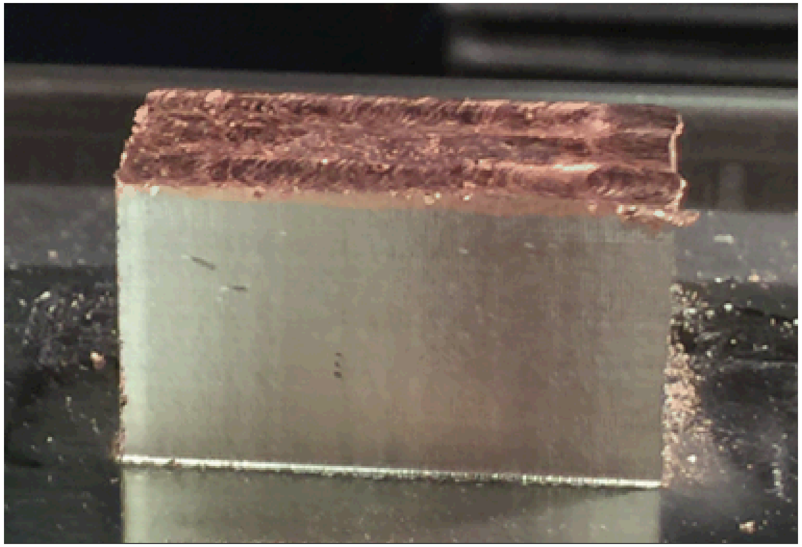


Thermal Concentrator Test Vehicles

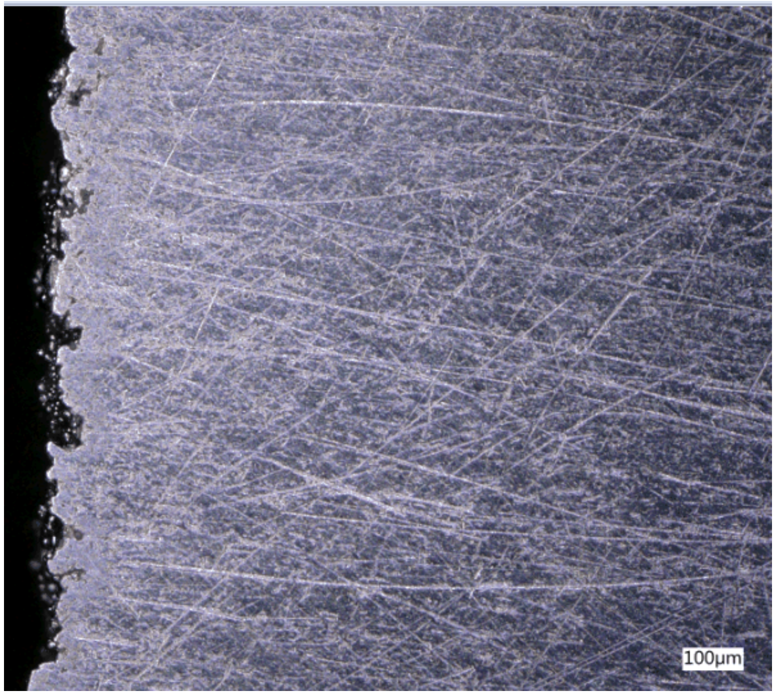
Hybrid AM – Additive/Subtractive

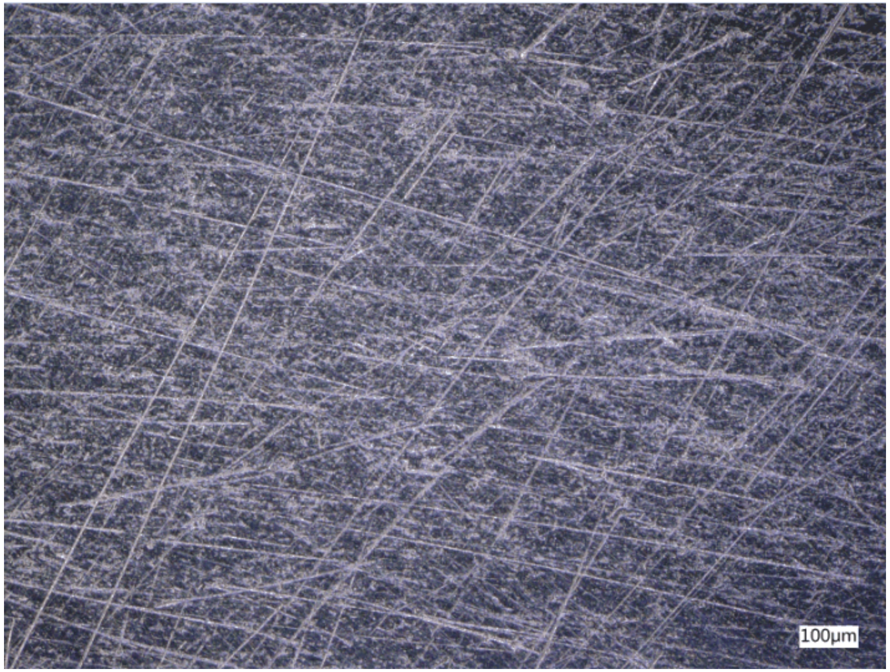






304L Cross-Sections



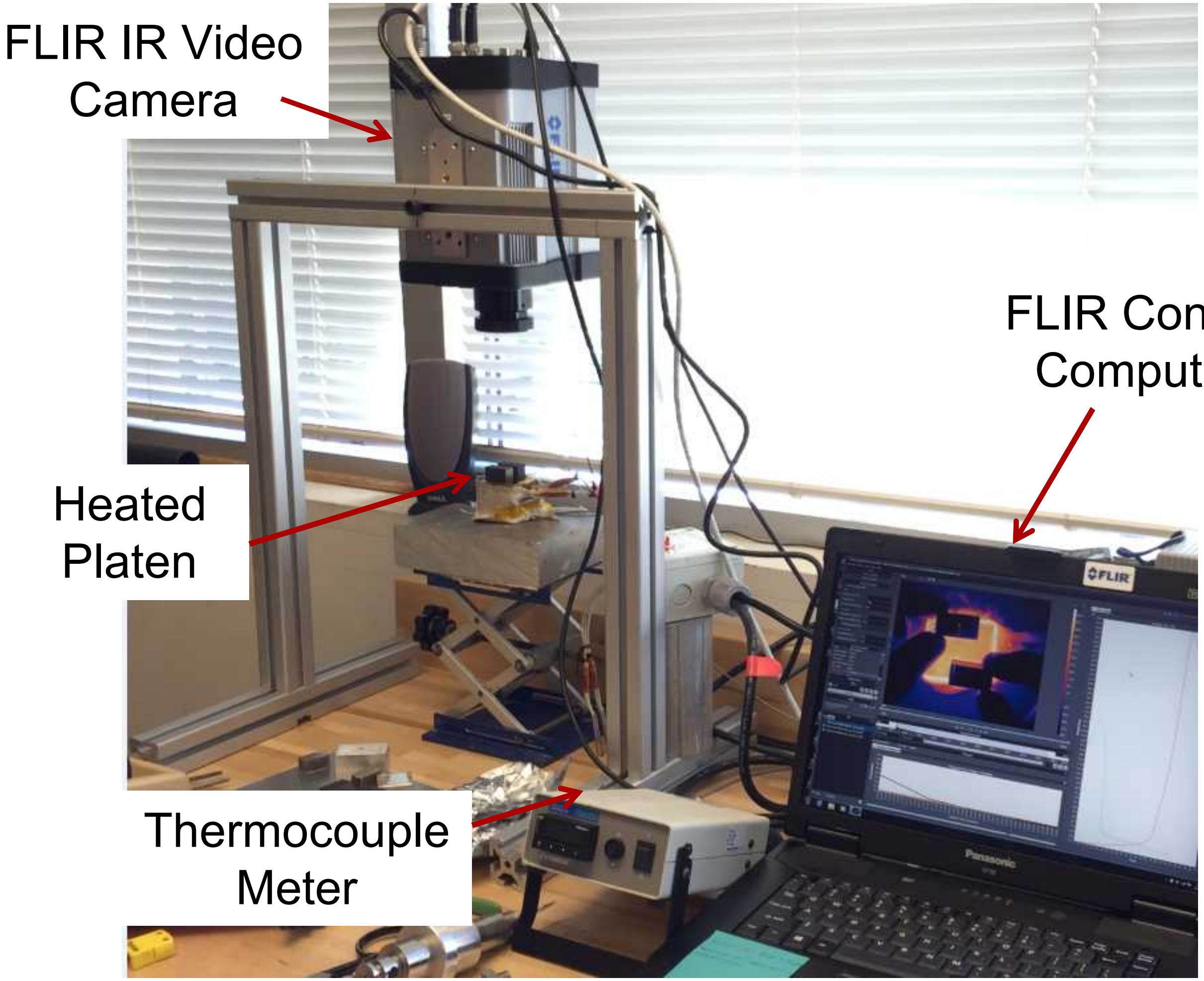


Sample cross-section taken close to substrate where porosity most likely to occur. Images show no sign of porosity.

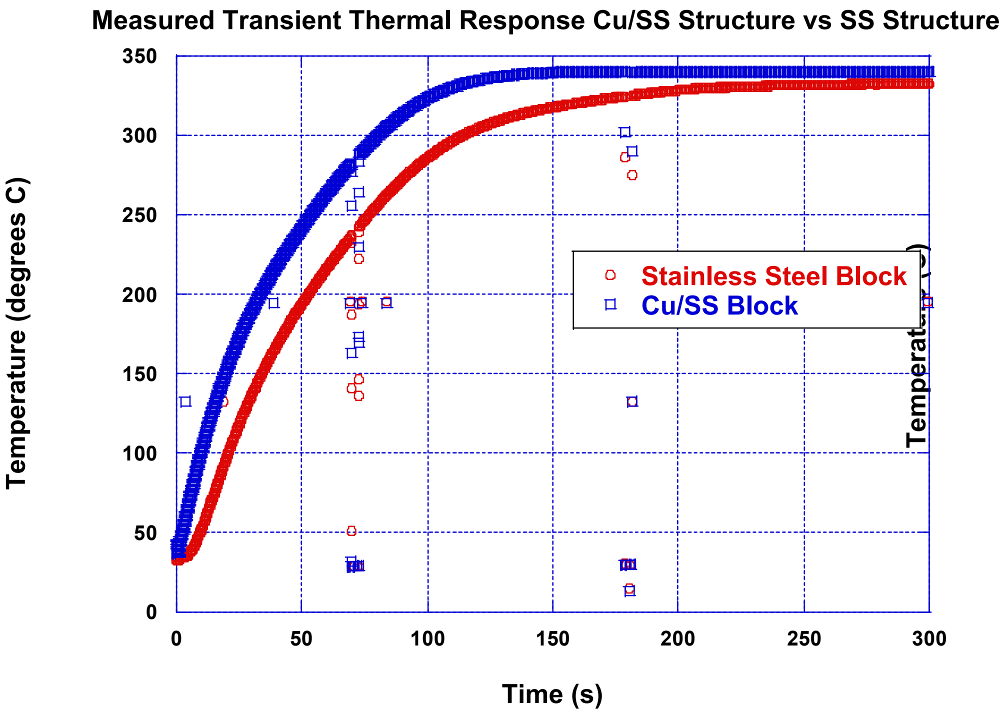
Transient Thermal Experiments

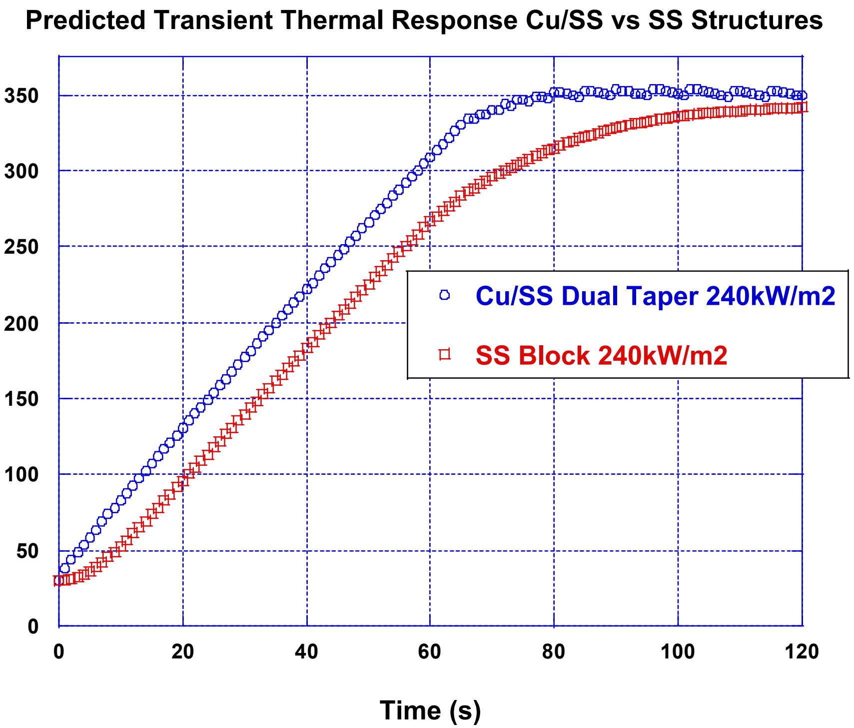
- 240,000 W/m^2 input energy to test parts
  - 2 – 200W cartridge heaters
  - Heater insulated on bottom and all sides
  - 38 x 44 mm heater surface area
- Heater preheated to 350° C
- FLIR recording started
- Top of parts painted to provide uniform emissivity
- Parts placed onto heater
- Transient thermal history recorded

Thermal Analysis Test Apparatus

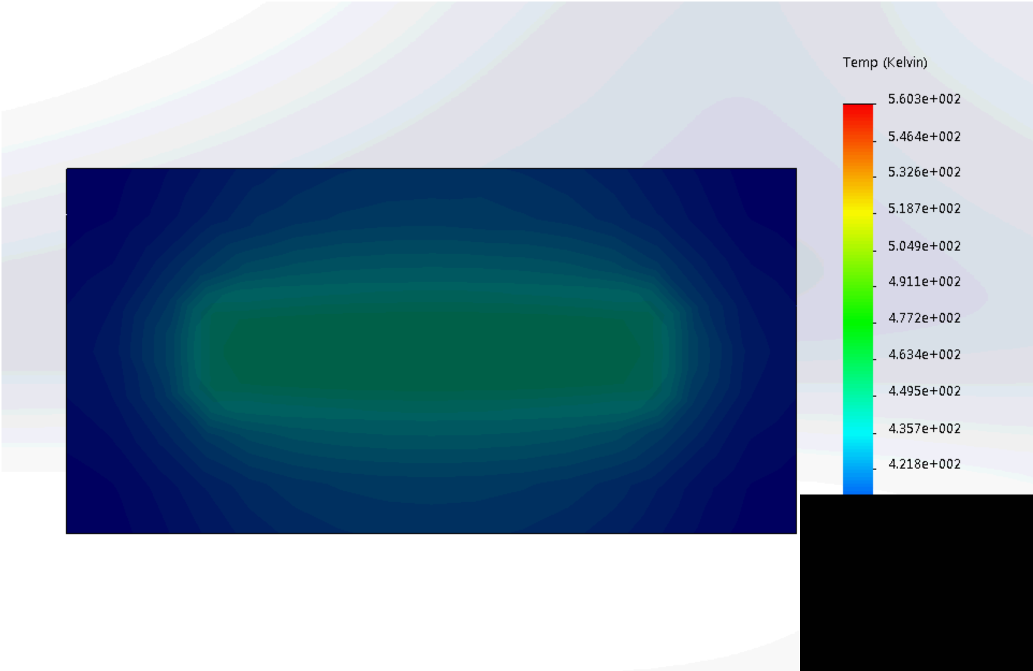


Measured Transient Response vs Predicted



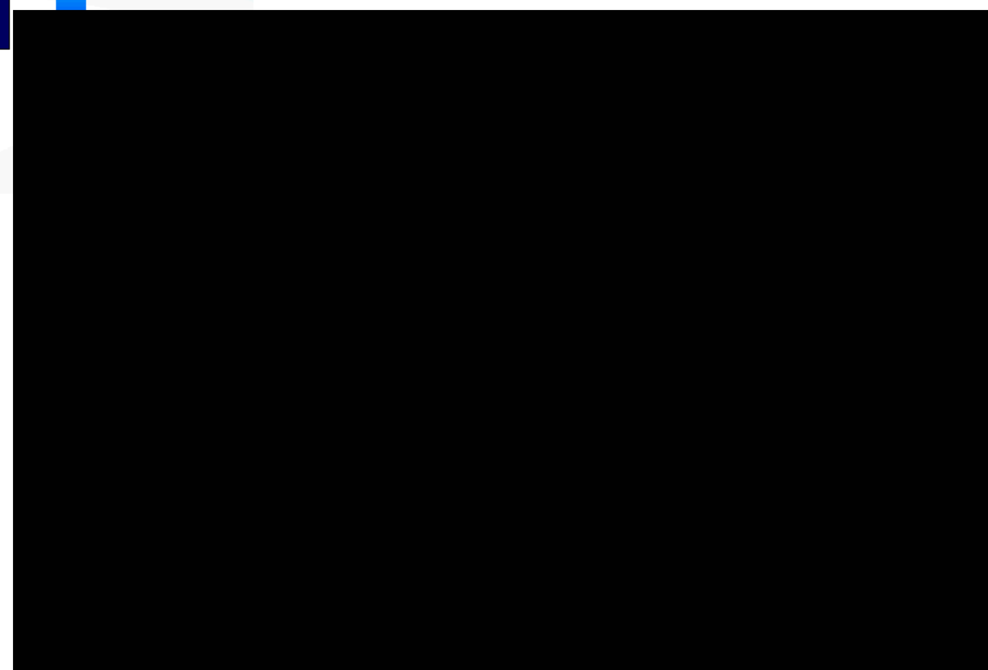


Simulation and Test Results – Thermal Concentrator



Simulation results for thermal concentrator test vehicle design 15s

IR video imaging showing thermal response of SS vs SS/CuC multimaterial thermal concentrator



Conclusions

- Application is tailored for AM
- Enables new design flexibility, not just as a traditional manufacturing substitute
- LENS process successfully created SS-CuC trial parts
- Fully customizable to match geometry and thermal response,
- Transient thermal conduction FEA and experiments show increased heat transfer
- Future Work:
  - Cross-sectional analysis
    - Stainless parts
    - Cu/SS parts for interface analysis
  - Tensile specimen results quantification
  - Thermal concentrator design optimization

Thank you

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Special Thank You To Daryl Dagel, Derek Reinholtz, and Shaun Whetten

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