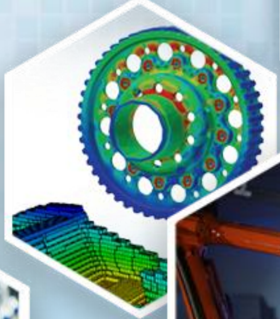
Material Characterization and Validation of Process Simulation for Large Scale Additive Manufacturing


Team:

Purdue (Eduardo Barocio, Vasudha Kapre, Miguel Ramirez, R. Byron Pipes)

Techmer (Alan Franc, Tom Drye)

Thermwood (Jason Susnjara)

Outline

- Introduction
- Summary of Material Characterization
- AM Process Simulations
- Experimental Validation of Process Simulations
- Conclusions

Project Overview

Challenge: Lack of material property information that is specific to the needs of the additive manufacturing.

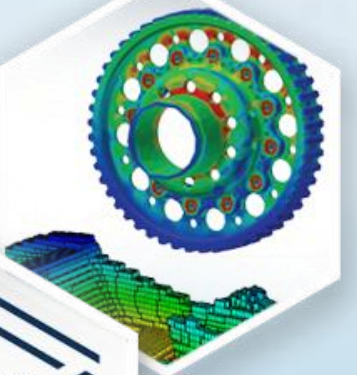
Approach: Extensive experimental and virtual characterization of commercial AM materials.

Develop digital material cards to enable process simulations of Large-Scale Additive Manufacturing.

Validate simulation predictions against experimental measurements.

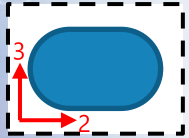
Impact: Accelerate the commercial deployment of Large-Scale AM by using simulation to drive design and to reduce the costly empirical process of finding printing conditions that will lead to successful prints.

Large Scale Additive Manufacturing



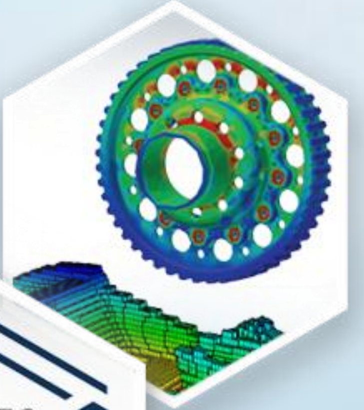
Material Characterization

Summary – Material Characterization



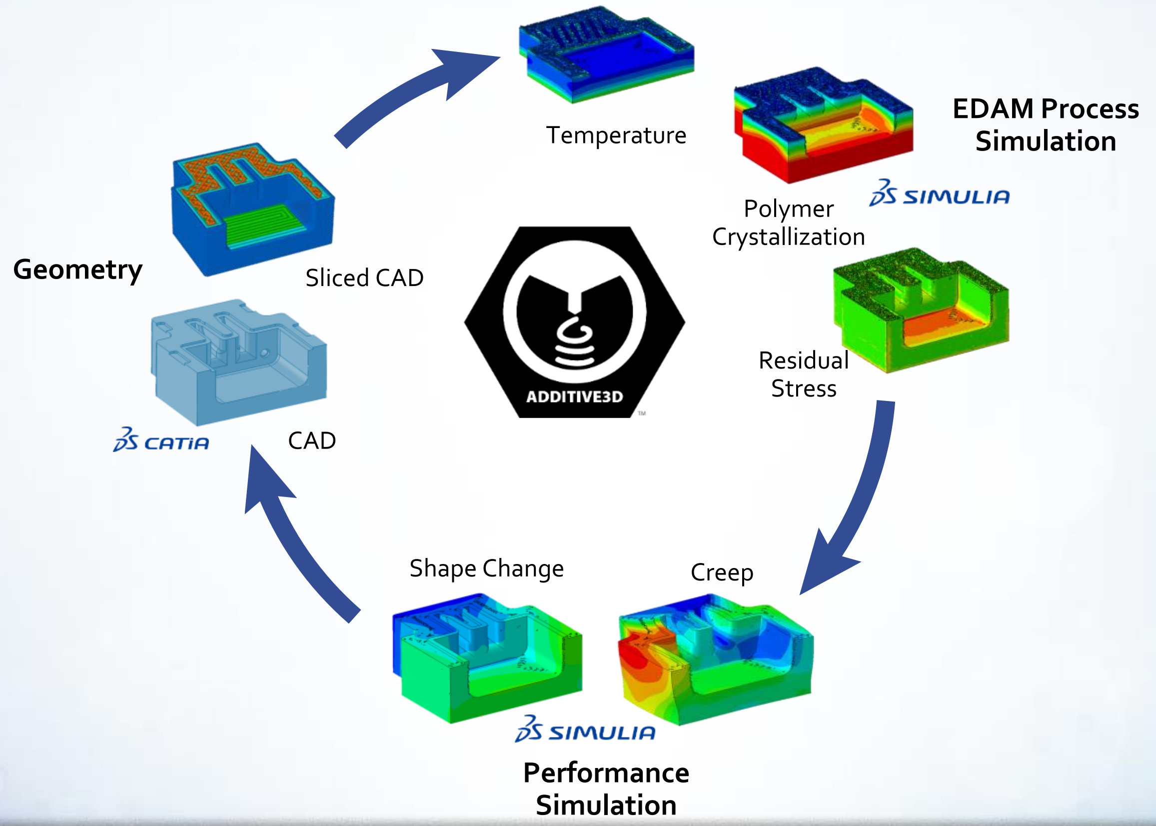
Material behavior homogenized at the level of the printed bead.

Material Property	Relevant Standard	50% CF-PPS 1501 3DP		25% CF-PESU 1810 3DP		25% CF-PSU 1901 3DP	
		Status	Expected Date to Complete	Status	Expected Date to Complete	Status	Expected Date to Complete
Tg - DMA	ASTM D7028	Completed		Completed		Completed	
Fiber Orientation Distribution		Completed		Completed		Completed	
Fiber Length Distribution		Completed		Completed		Completed	
Tensile Properties (Stacking Direction)	ASTM D3039	Completed		Completed		Completed	
Tensile Properties (Printing Direction)	ASTM D3039	Completed		Completed		Completed	
Tensile Properties (Transverse Direction)	ASTM D3039	Completed		Completed		Completed	
Shear Properties	ASTM D5379	Completed		Completed		Completed	
CTE in the three directions as function of temperature	ASTM E831	Completed*		Completed		Completed	
Crystallization Kinetics and Melting (DSC)		Completed		NA		NA	
Viscoelastic Characterization (DMA)	ASTM D5023	Completed		Completed		Completed	
Thermal Conductivities & Heat capacity	ASTM E1461 & ASTM E1269	Completed		Completed		Completed	

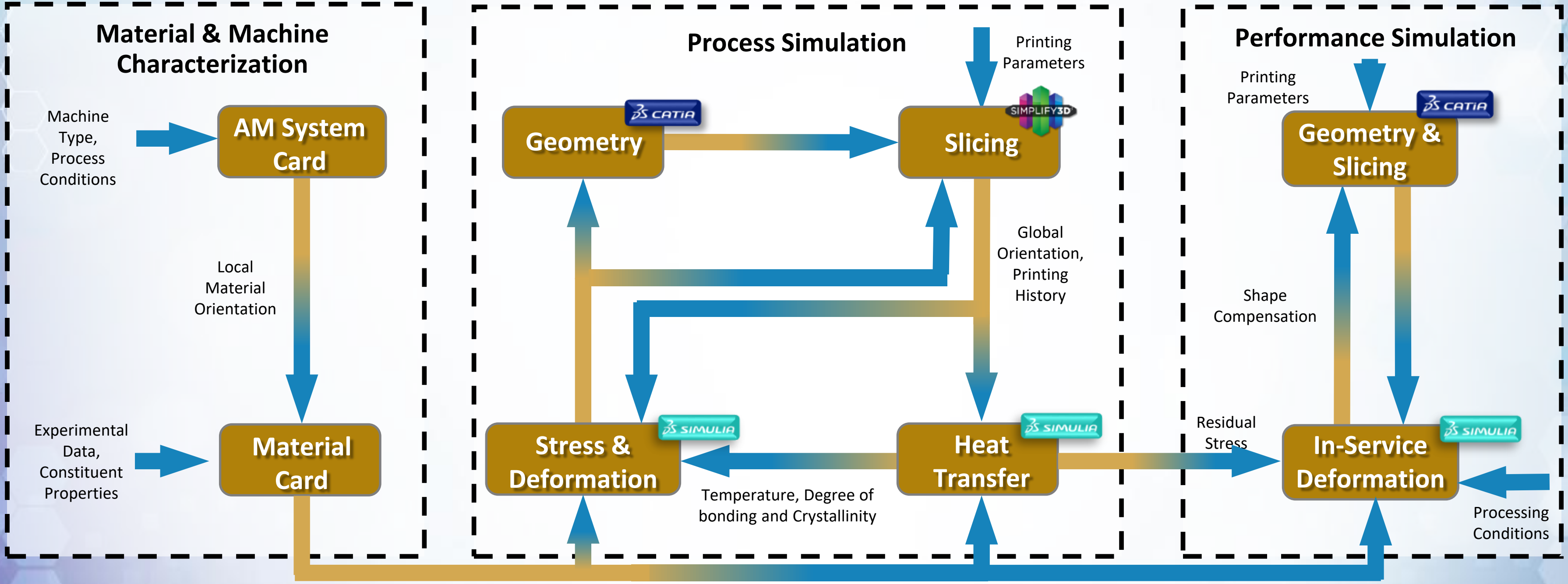


AM Process Simulation

Simulation Workflow for EDAM



Additive Simulation Workflow

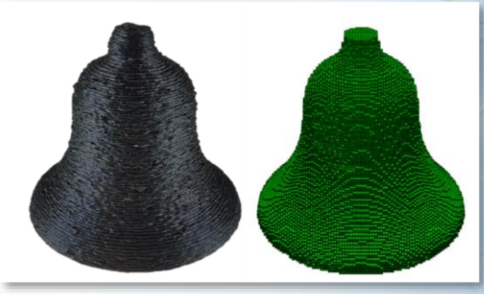


Additive Simulation in Abaqus

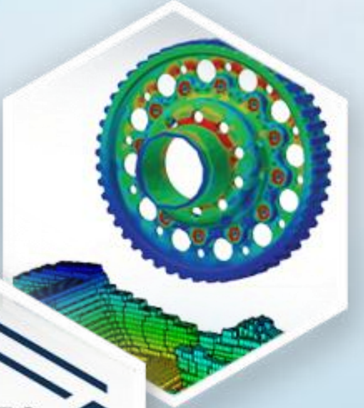
- Elements activated based on machine code (EPA - UEPActivation)
- Material orientation assigned based on printing trajectory (Orient)
- Material models and boundary conditions implemented through
  user subroutines:

Physical Phenomenon	User Subroutine
Orthotropic Heat Transfer Polymer Crystallization/Melting Interlayer Fusion Bonding	UMATHT
Local film and radiation conditions	UFIELD
Heat losses from compactor	UMDFLUX
Anisotropic Shrinkage Crystallization Shrinkage	UEXPAND
Viscoelasticity	UMAT

Inactive,
Part-Unspecific
Mesh



Element
Activation
Based
on Machine
Code

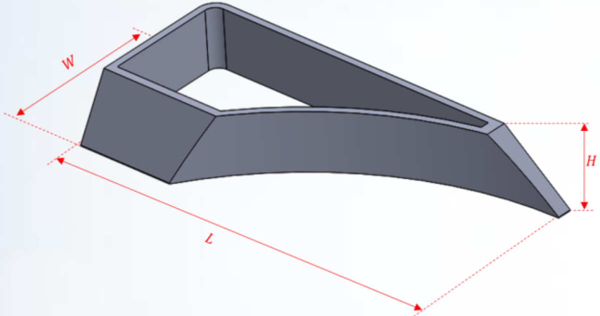


AM Process Simulation

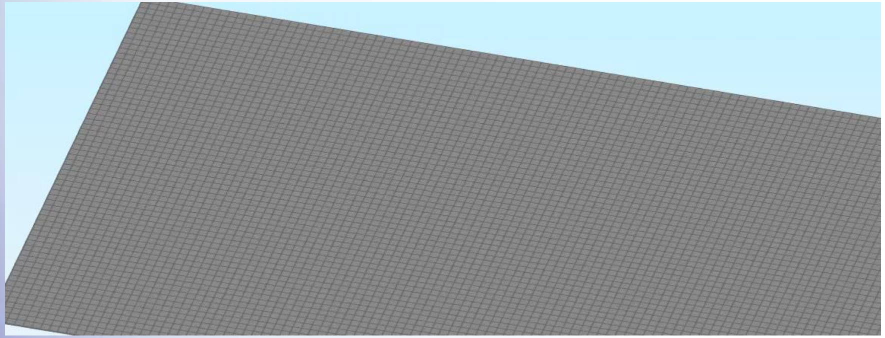
Experimental Validation

Geometries for Validating Process Simulations

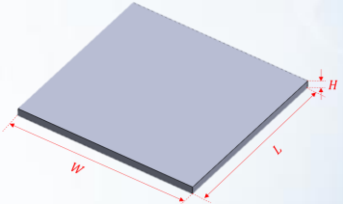
Curved Wedge



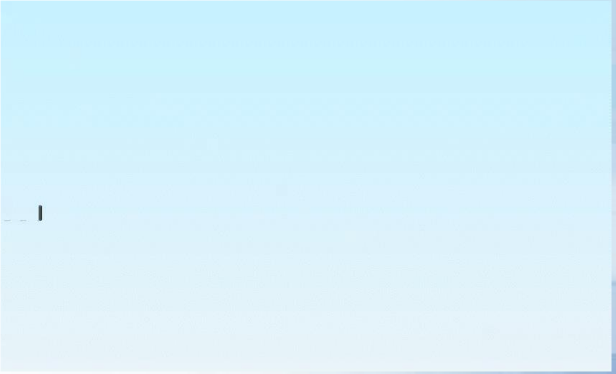
Dimensions (W x L x H) : 254.0 x 254.0 x 6.0 mm (10.0” x 10.0” x 0.24”)



$[0_2/90_2]$ Plate



Dimensions (W x L x H) : 254.0 x 254.0 x 6.0 mm (10.0” x 10.0” x 0.24”)

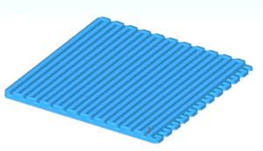


Experimental Validation

Techmer – 50% wt. Carbon Fiber-Reinforced Polyphenylene Sulfide (PPS)

Process Simulation – Plate CF-PPS

Inputs



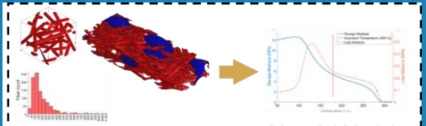
Machine Code

CAMRI Composites Additive Manufacturing Research Instrument

LSAM Large Scale Additive Manufacturing

CI BAAM

AM System Card



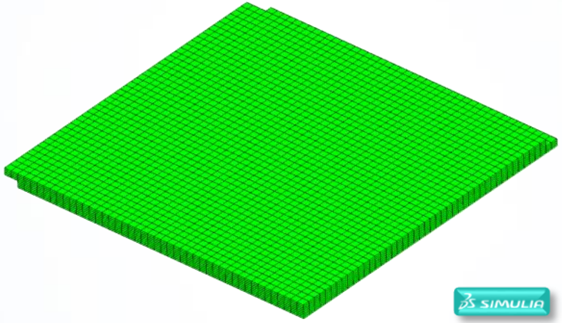
Digital Material Card

Global Fiber Orientation

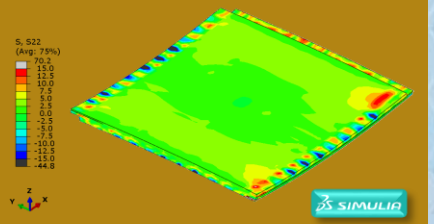
Boundary Conditions

Material Models

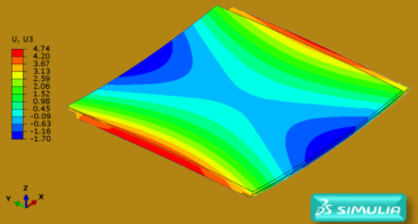
FEA Process Simulation



Outputs



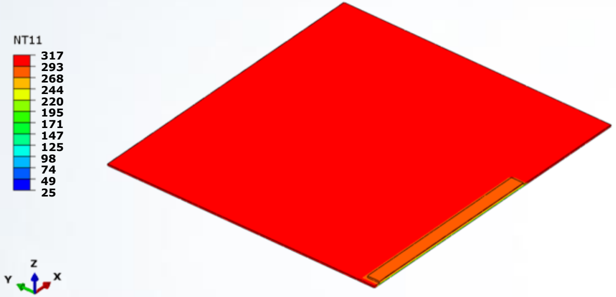
Residual Stress



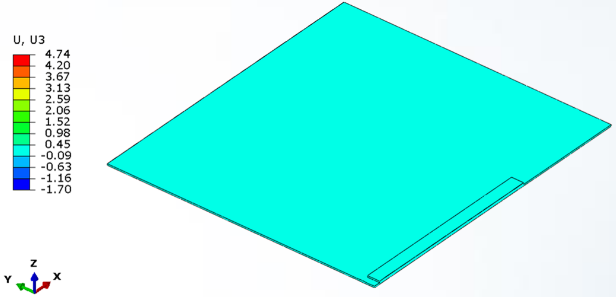
Deformation

AM Process Simulation Plate – CF-PPS

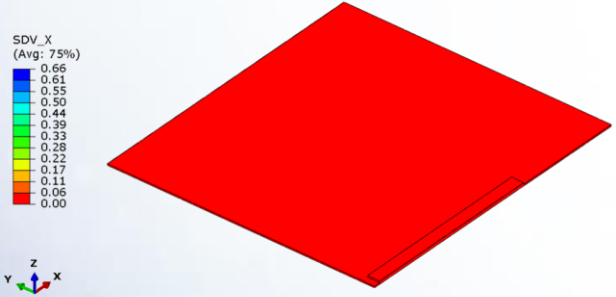
Temperature - (℃)



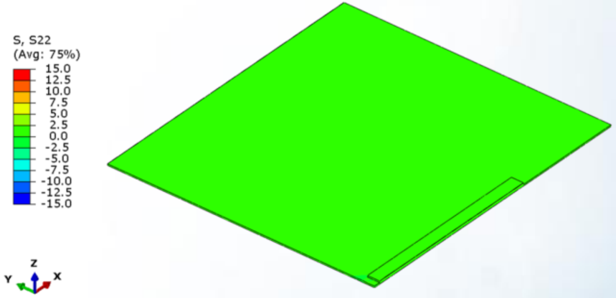
Deformation - U_3 **(mm)**



Crystallinity (%)



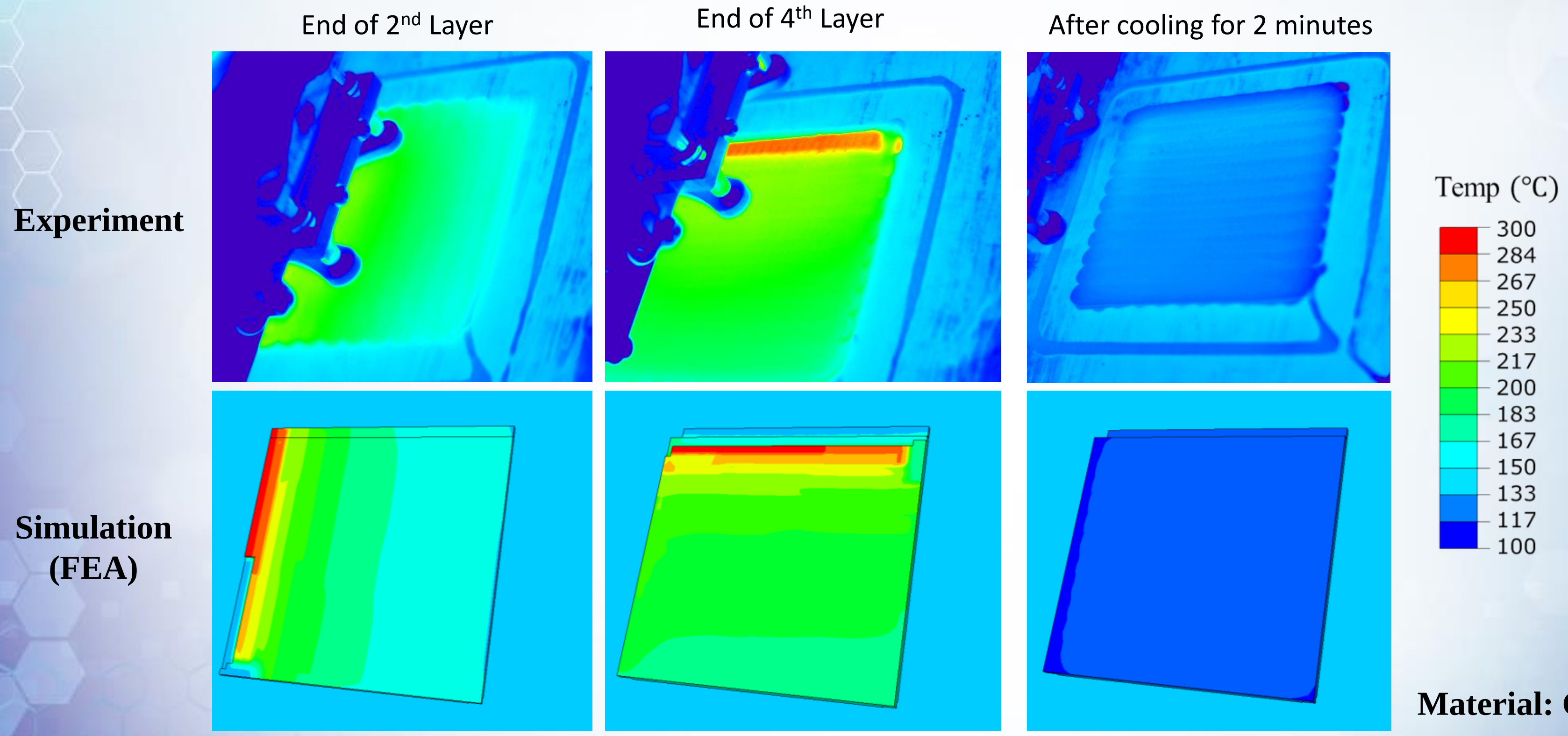
Stress - σ_{22} **(MPa)**



Speed ~10X

Material: CF-PPS

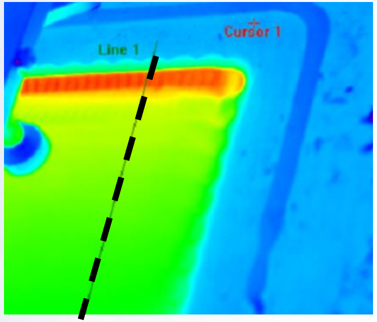
Verification of Temperature Fields



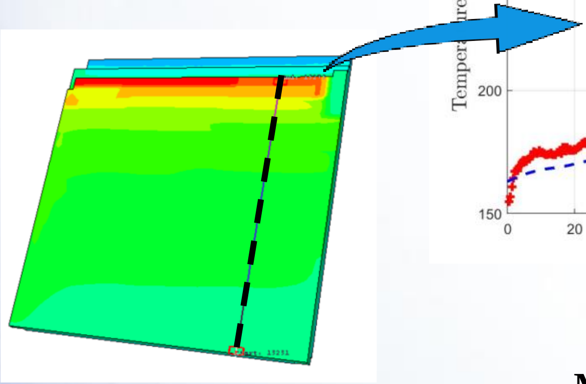
Material: CF-PPS

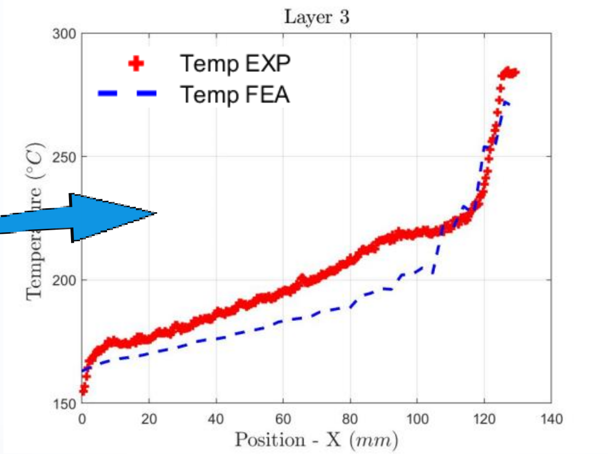
Validation of Temperature Profiles

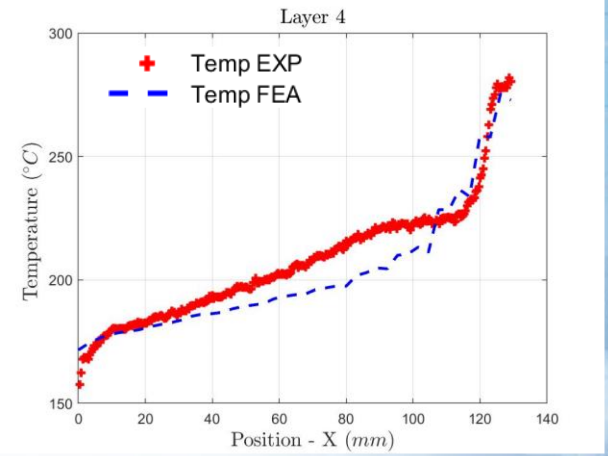
Experiment



Simulation (FEA)

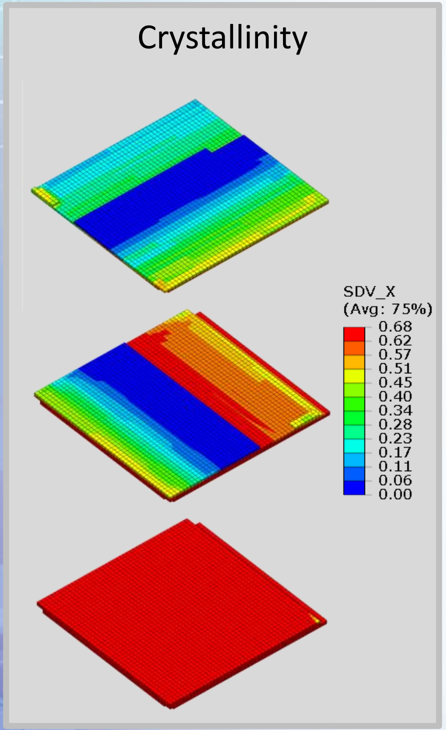




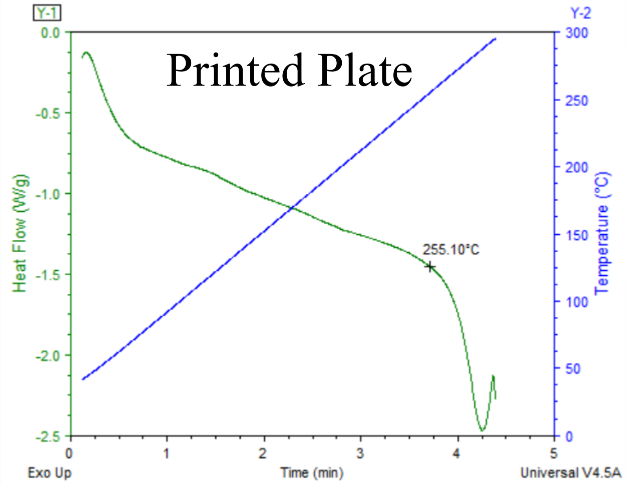


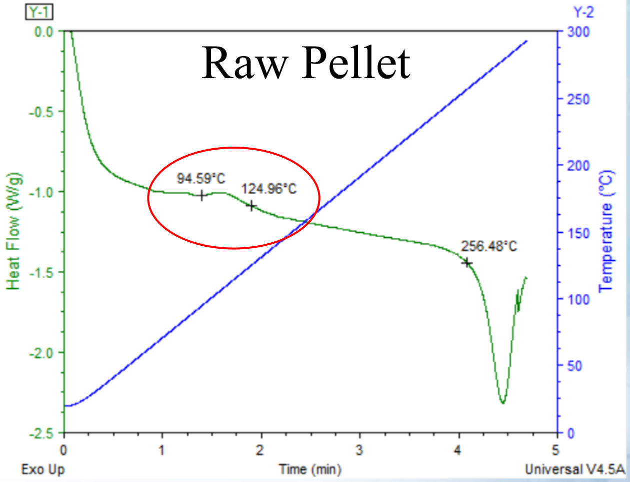
Material: CF-PPS

Verification of Degree of Crystallinity



- Plate developed full crystallinity after printing process
- No cold crystallization observed on DSC tests of material extracted from printed plate

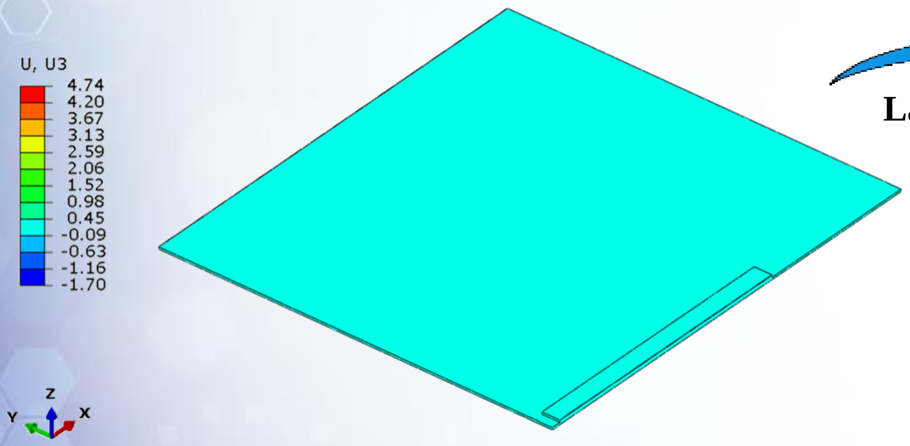




Validation of Shape Deformation

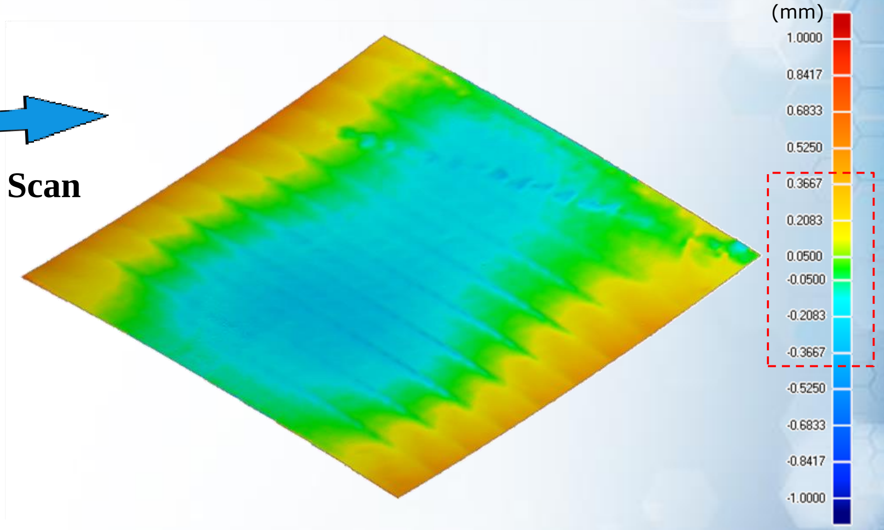
Process Simulation

Deformation - U_3 (mm)



Laser Scan

Deviation: Simulation vs Experiment

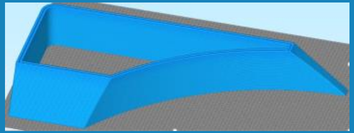


Material: CF-PPS

Process Simulation – Curved Wedge CF-PPS

THE COMPOSITES iacmi INSTITUTE

Inputs



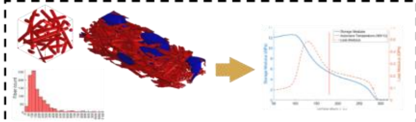
Machine Code

Global Fiber Orientation

CAMRI
Composites Additive Manufacturing Research Instrument
LSAM
Large Scale Additive Manufacturing
CI BAAM

AM System Card

Boundary Conditions



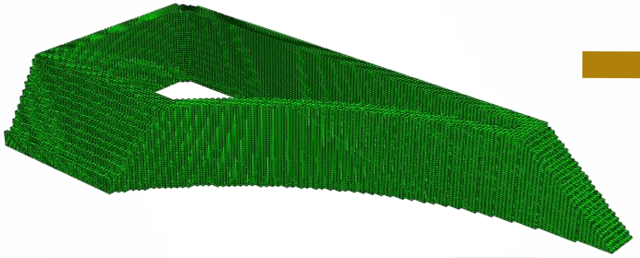
Property Prediction

Material Models

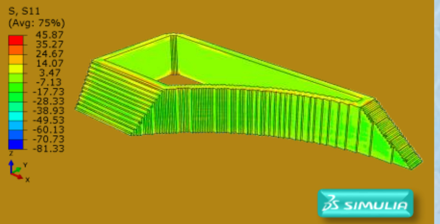
Digital Material Card

Material Models

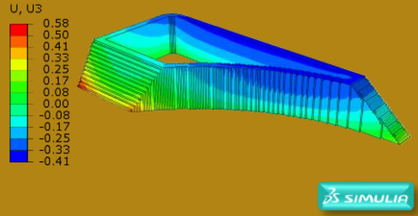
FEA Process Simulation



Outputs



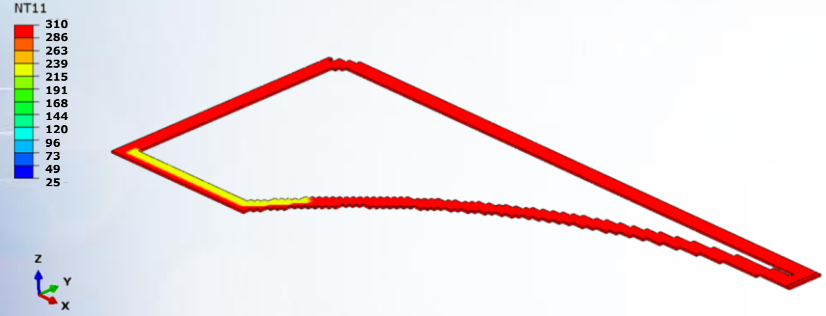
Residual Stress



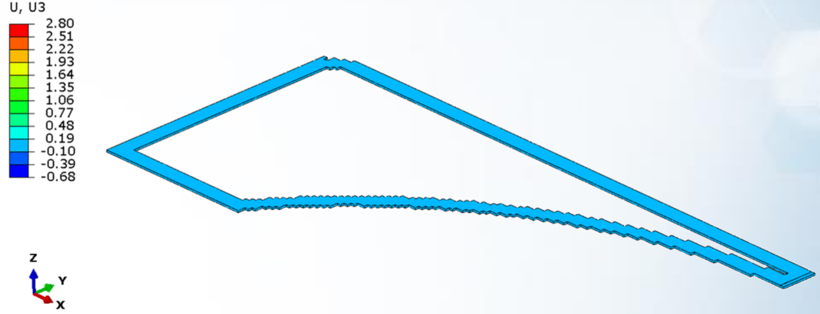
Deformation

Process Simulation Results

Temperature - (℃)

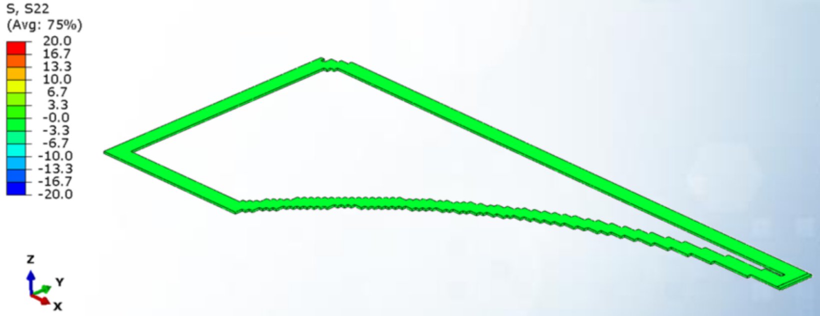


Deformation - U_3 (mm)



Crystallinity (%)

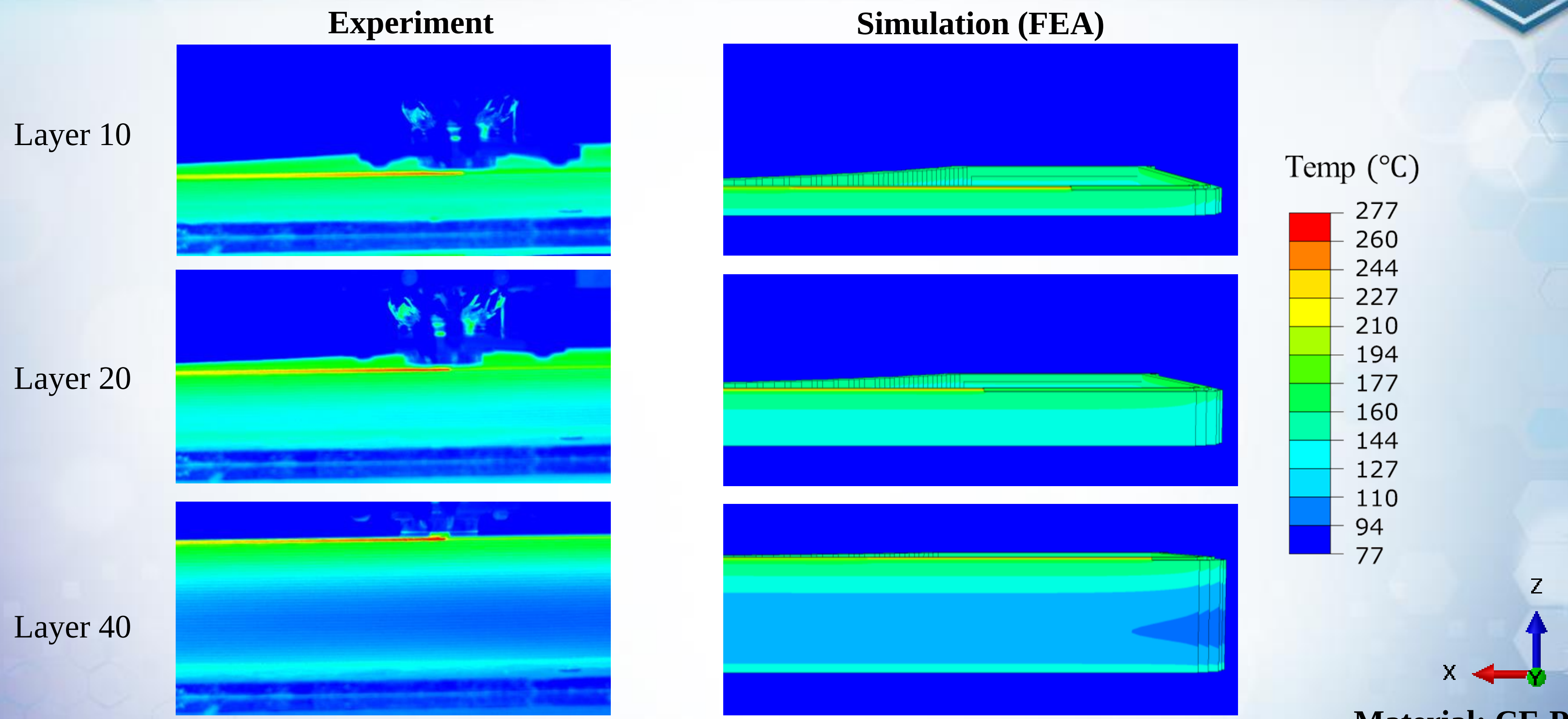
Stress - σ_{22} (MPa)



Speed ~60X

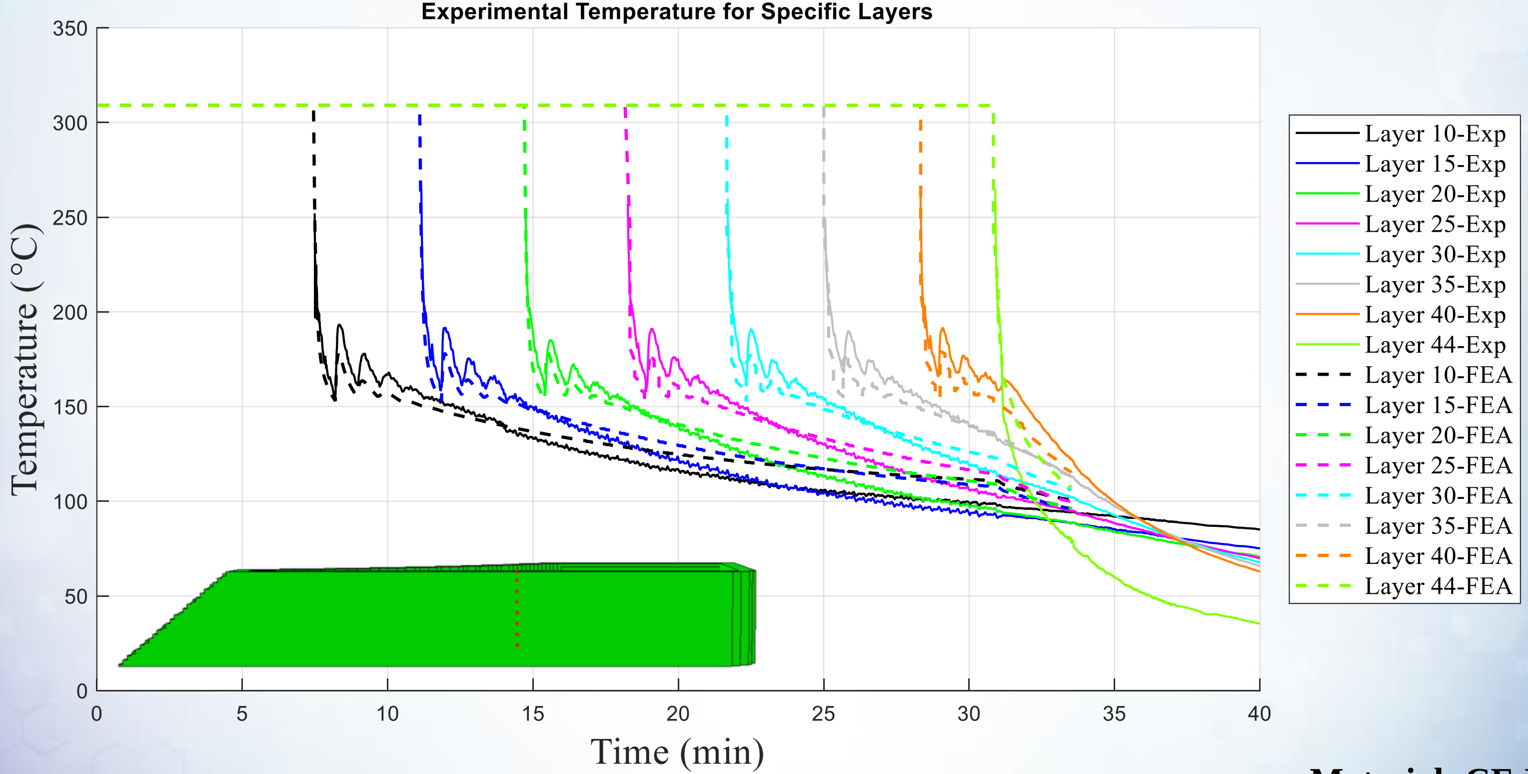
Material: CF-PPS

Verification of Temperature Fields



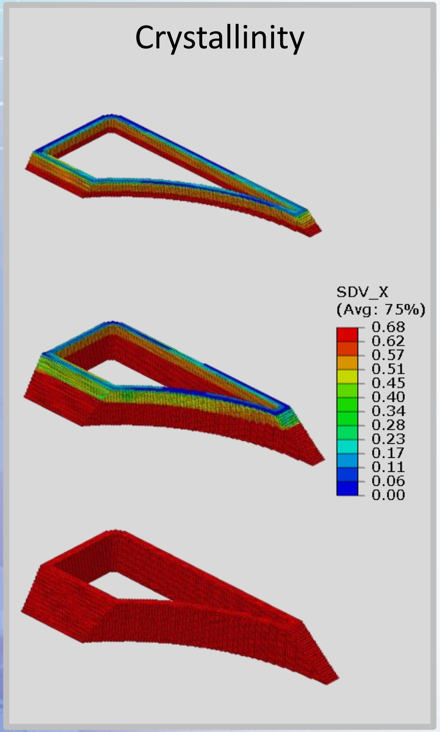
Material: CF-PPS

Validation of Temperature History

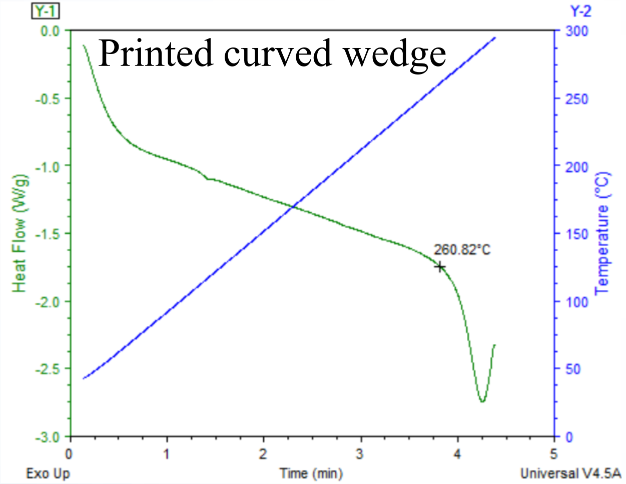


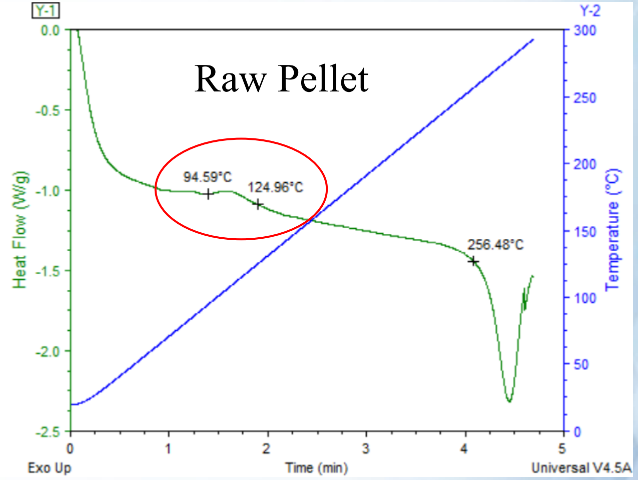
Material: CF-PPS

Verification of Degree of Crystallinity



- Curved wedge developed full crystallinity after printing process
- No cold crystallization observed on DSC tests of material extracted from printed plate

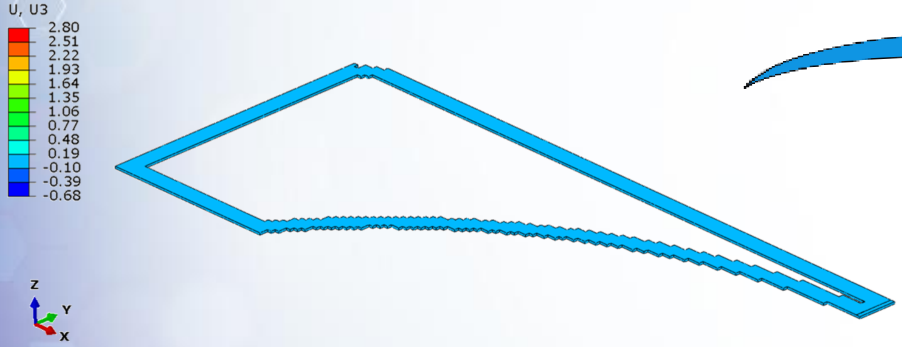




Validation of Shape Deformation

Process Simulation

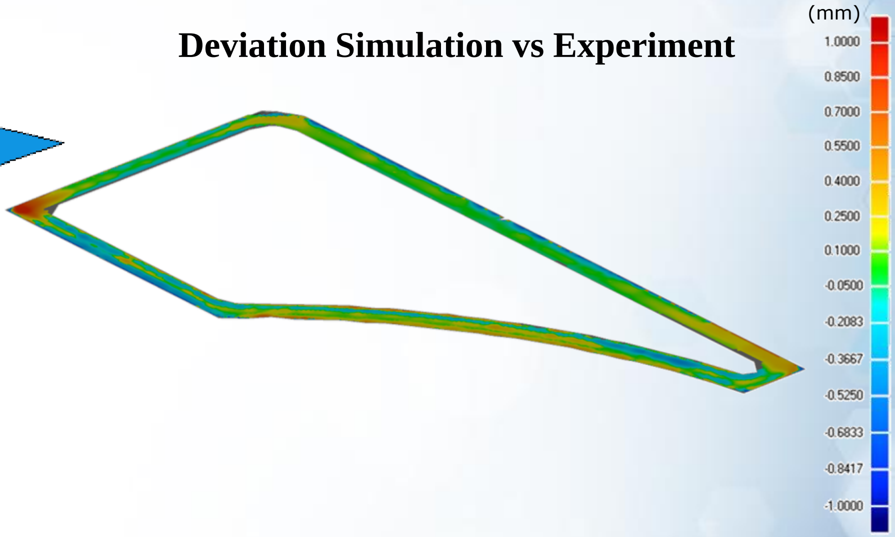
Deformation - U_3 (mm)



Speed ~60X

Laser Scan

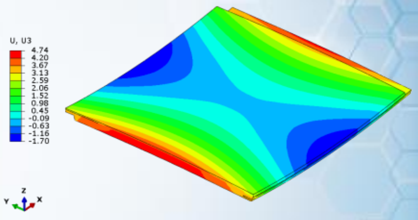
Deviation Simulation vs Experiment

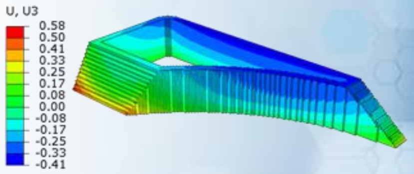


Material: CF-PPS

Technical Conclusions

- Extensive material characterization was carried out for 50% CF-PPS, 25% CF-PSU, 25% CF-PESU.
- Digital material cards were generated for the three material systems which enable virtual investigations of process parameters used in the EDAM process.
- Two geometries were used for validating the simulation predictions made with Additive3D.
- Temperature fields and temperature time history predicted through process simulations were in great agreement with the experimental measurements.
- Shape deformation predicted with the process simulation was in great agreement with the experimental measurements (<10% deviation).
- Status: Finalizing report that includes validation of other material systems and comparison between the deformation developed with the different material systems.





Program Conclusion

- This IACMI project demonstrates a successful collaboration between material supplier, equipment manufacturer, and academic research center to deliver research and development results to speed up the rate of technology adoption.