Thermoplastic Composites Conference

In-Situ Consolidation of Thermoplastic using Automated Fiber Placement

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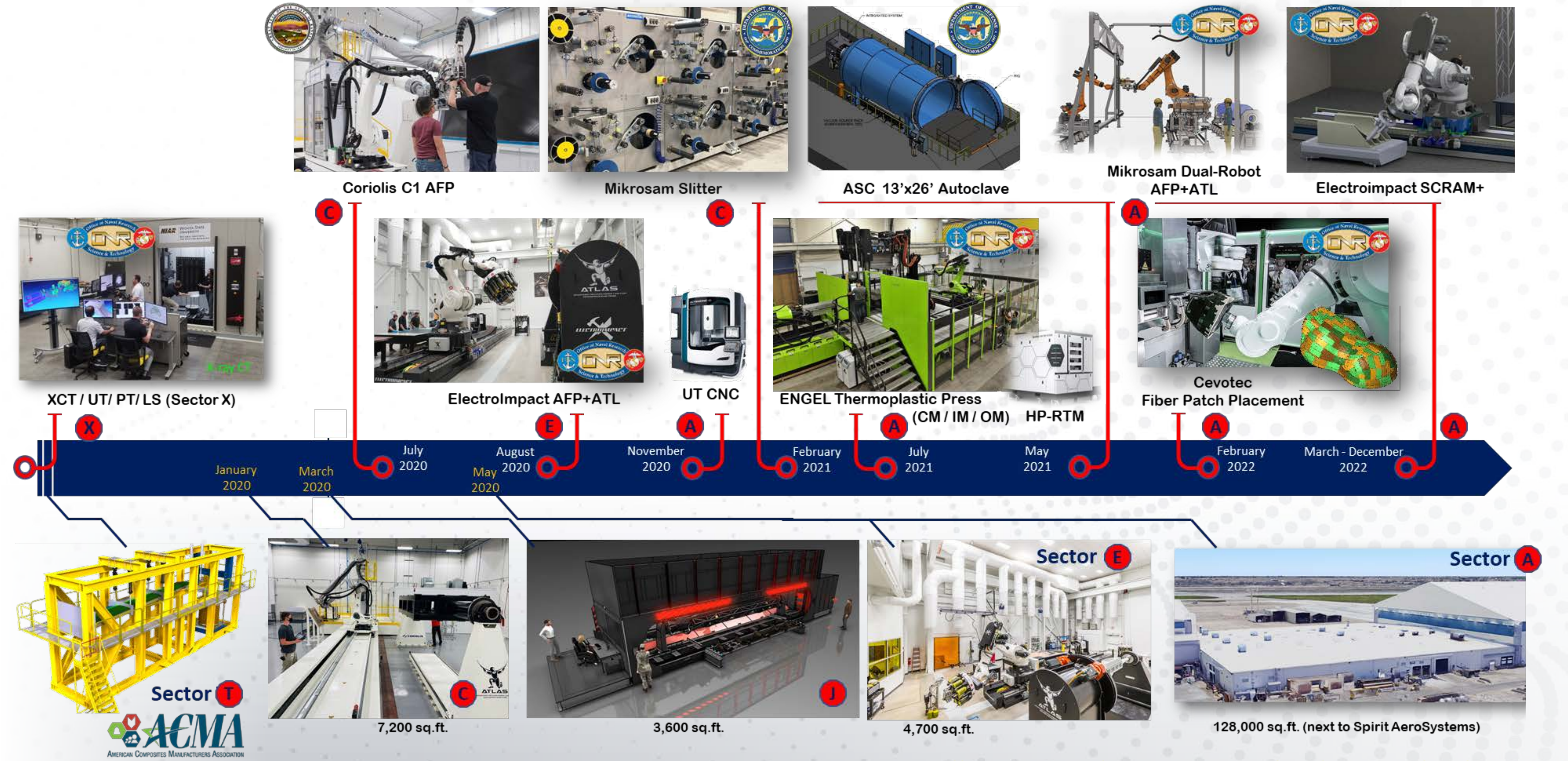
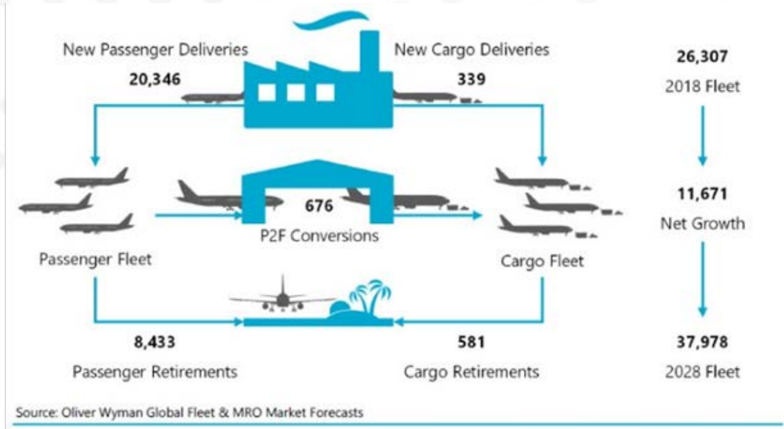
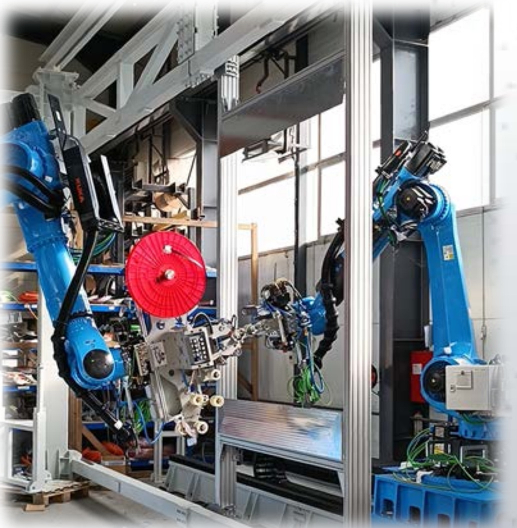


https://www.wichita.edu/industry_and_defense/NIAR/Laboratories/atlas/atlas.php

Background

- Aircraft manufacturing processes will be required to undergo significant technology advancements to increase production rates.
- Recent advances in thermoplastic material heating technologies like laser and pulsed light solutions has enabled the use of thermoplastics in automated fiber placement (AFP) processes.
- Further process optimization via in-situ consolidation eliminates the need for secondary processing, which significantly reduces manufacturing costs and increases production rates.



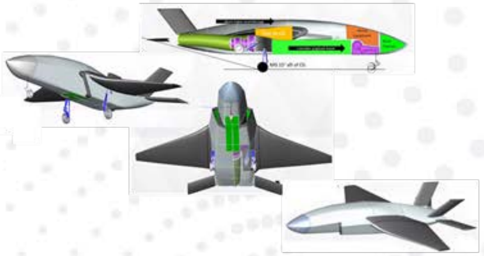


Main goal of this research task is to develop protocol for in-situ consolidation of AFP thermoplastics (ICAT).
Protocols will be expanded for using thermoplastics for in-space manufacturing with multi-robotic tool-less AFP process.

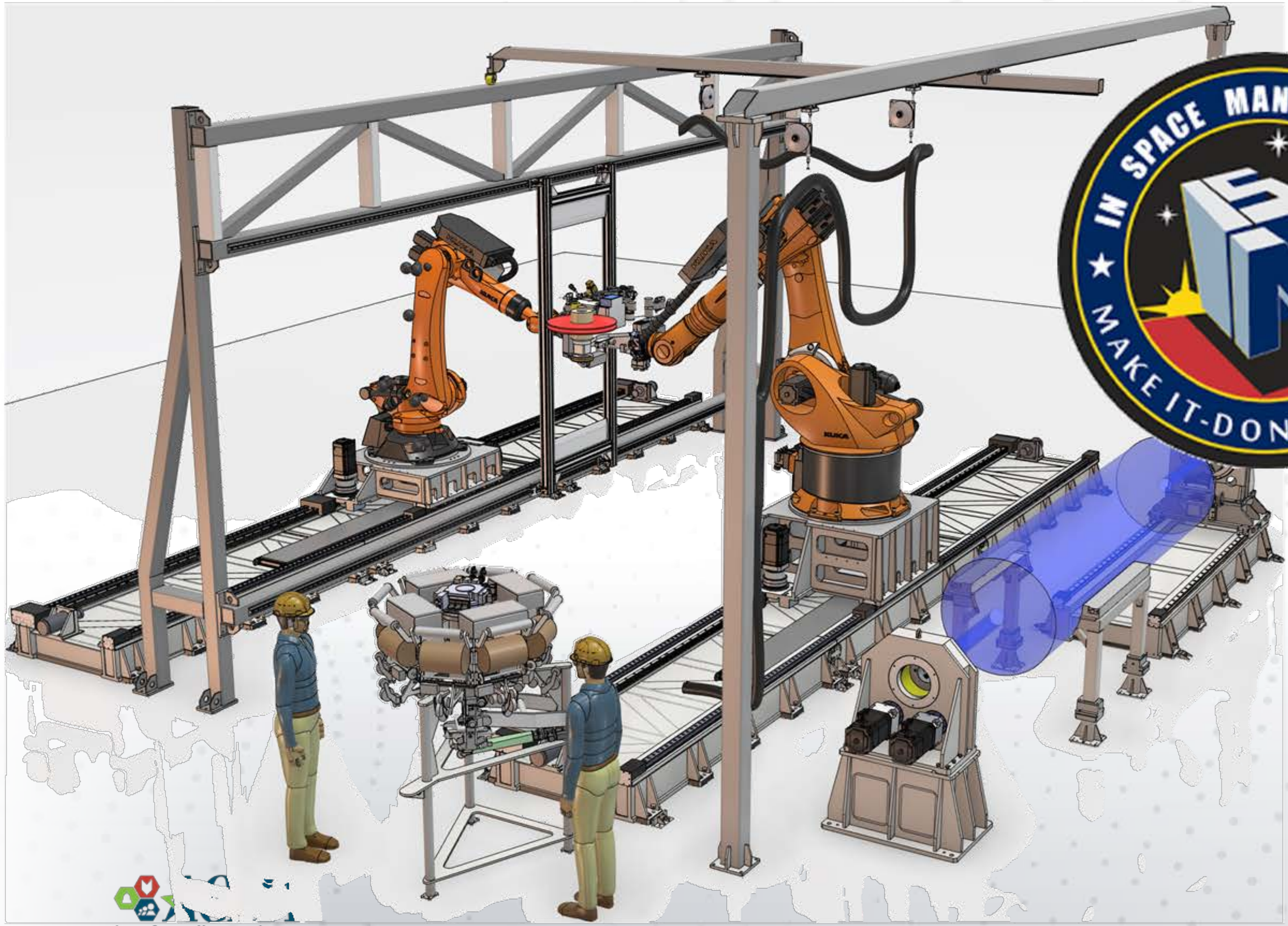
Thermoplastic Research at NIAR ATLAS

Modeling for Affordable Sustainable Composite (MASC)

- Automated fiber placement (AFP)
  - NCAMP qualifications
  - In-situ consolidation
  - Tool-less manufacturing
- Scalable Composite Robotic Additive Manufacturing (SCRAM)
- Fusion welding
- Over-molding
- Material characterization
- Lightening strike material evaluation

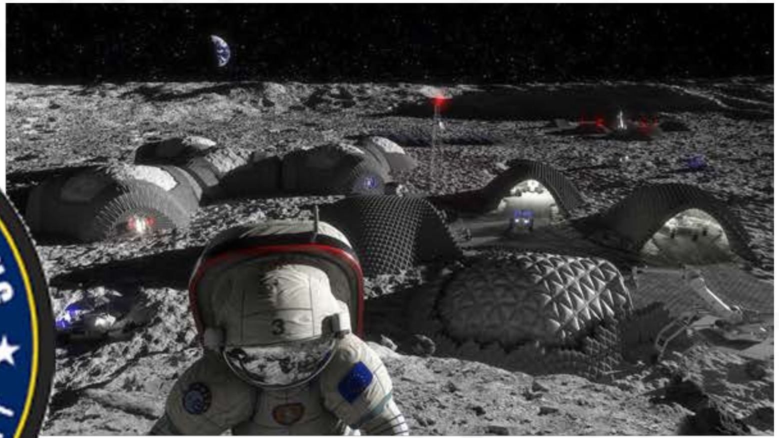


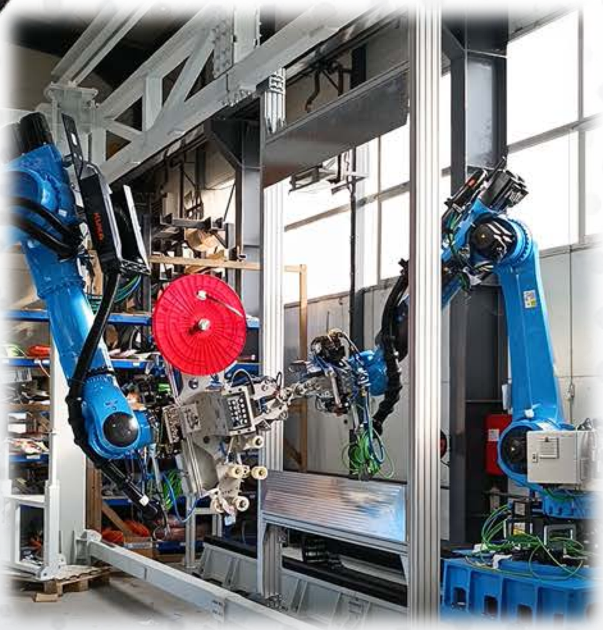
Tool-less Manufacturing In Space



IN SPACE MANUFACTURING

MAKE IT-DON'T TAKE IT





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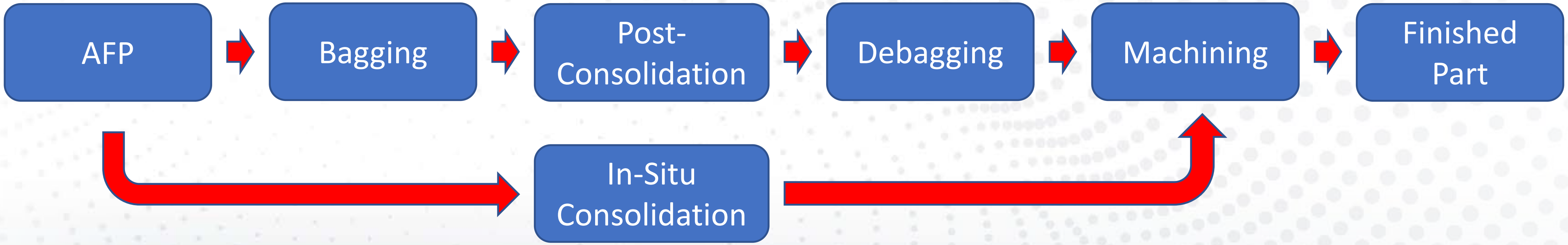
Thermoplastic AFP Post- vs. In-Situ Consolidation

- During automated fiber placement (AFP), thermoplastic tape and substrate are heated using laser and fused together while applying pressure.
- In order to achieve final consolidated ply thickness (CPT) and reduce porosity, post-AFP consolidation in an oven/autoclave is utilized.
- Process cycle (especially the cooling rate) is developed to achieve proper crystallinity to improve interfacial bond strength.



- In-situ consolidation eliminates secondary processes (increase production rate) and decreases cost

ICAT Road Map

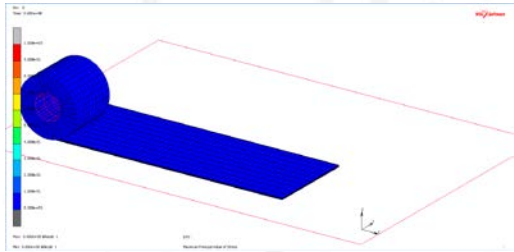
In-Process Monitoring Temperature & Pressure

Automated Fiber Placement (AFP) Trials

Thermo-Viso-Elastic Stress Analysis

Model Validation

Process Optimization



Development of AFP Process

Slit Tape Quality Assessment

Fast Rate (Standard) AFP Flat Panel Fabrication

Autoclave/Oven Post Consolidation

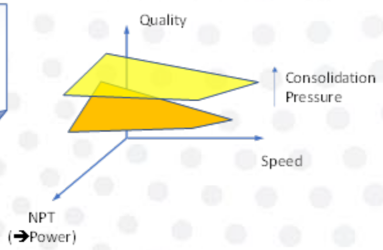
Slow Rate AFP Flat Panel Fabrication for In-Situ Consolidation

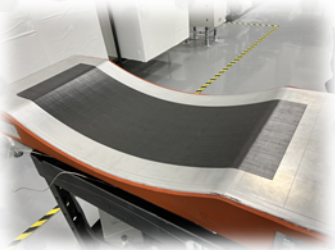
Nondestructive Inspections

Comparison of Physical, Thermal, and Mechanical Properties

1. AFP speed
2. Consolidation pressure
3. Thickness limitations
4. Laser/Humm3 power
5. Tool temperature (heated vs. non-heated tools)
6. Various AFP roller materials
7. Fiber steering
8. Different AFP Machines

1. DSC
2. NDI (PM, XCT)
3. SBS
4. Compression
5. Flexure
6. Mode I

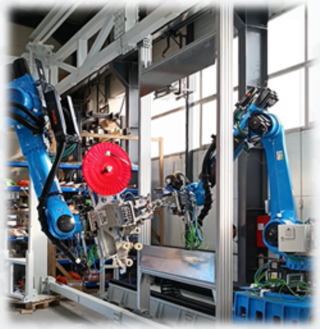




Development of AFP In-Situ Consolidation Process (Flat Panels)

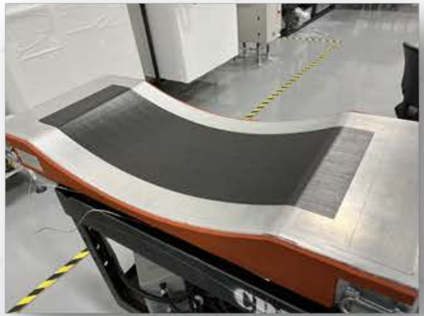
Development of AFP In-Situ Consolidation Process (Curved Parts)

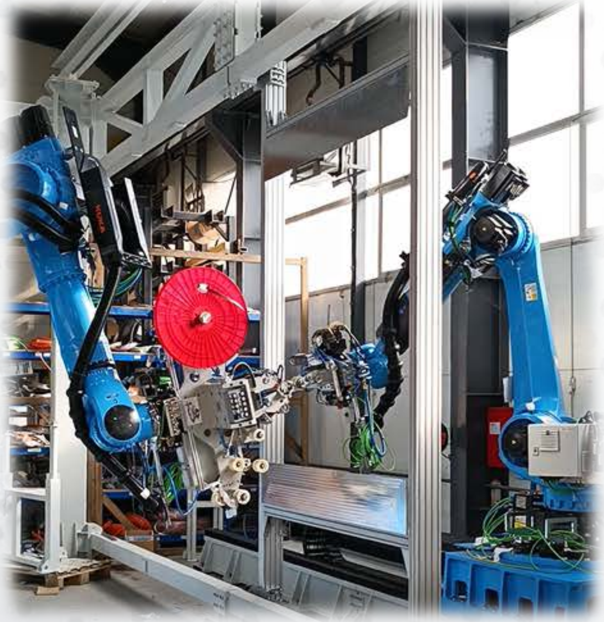
Tool-less Manufacturing

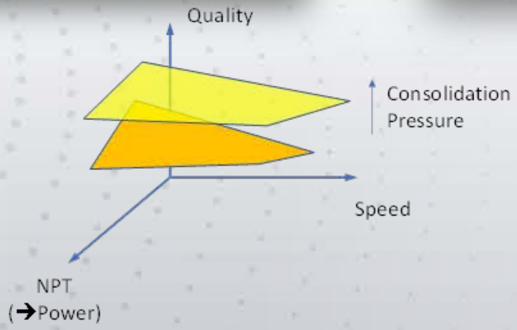


In-situ Consolidation & Secondary Heating (ICASH) Process Development

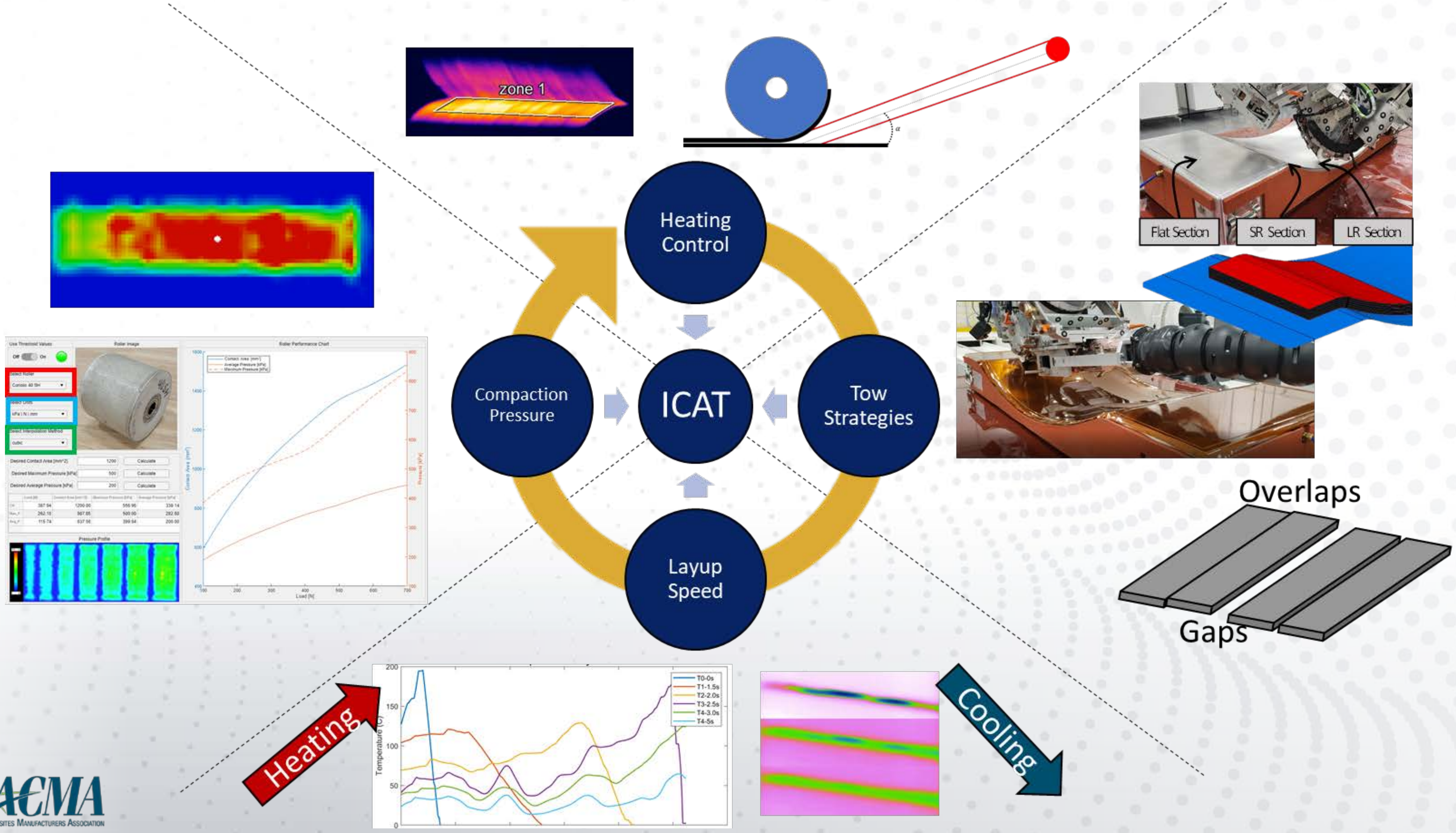
	Baseline*	Fairing		Fuselage Panel	Dual-Robot AFP	
Tool	Yes	Yes		Yes	No	
Tool Heating	Yes	Yes	No	No	No	
Curve	No	No	Yes	Yes	No	Yes
Equipment	AFP+Press AFP+AC/Oven	EI-1 (Laserline), EI-2 (VSSL), Coriolis, and Mikrosam		EI-1 (Laserline), EI-2 (VSSL), and Coriolis	Mikrosam	



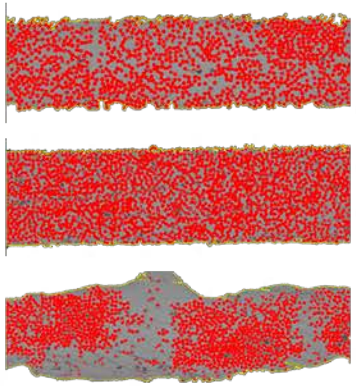


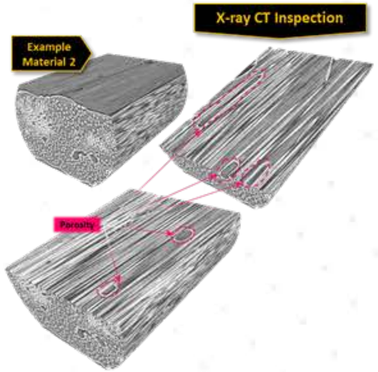


AFP Parameters and Processing



AFP Material Characterization





Material Type	Vendor	Number / Name	Composition	GSM	Slit-Width
Thermoset	Solvay	30202946	IM7/5320-1	145	½”
	Toray	P172EBN-19	T1100G/3960	192	¼”
Dry Fiber Infusion	Solvay	TX1105	IMS65/EP2400	280	¼”
	Hexcel	HITAPE	IM7/1078-1	280	¼”
Thermoplastic	Victrex	AE250	IM7/LMPAEK	148	¼”
	Solvay	APC	AS4D/PEKK-FC	145	¼”
	Toray	TC1225	T700/LMPAEK	145	¼”

Phase 0: Slit Tape Receiving Inspection & Effects of Defects

Phase I: Material Screening

Phase II: Machine Variability & Alternative Heat Sources

Phase III: Head Configuration (Q8, H8, and ATL)

Phase IV: NCAMP Process Specifications

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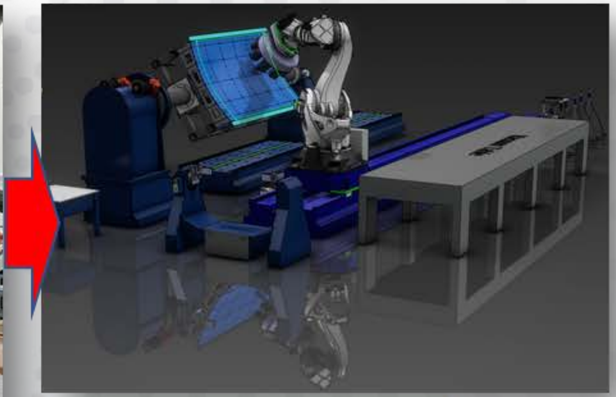
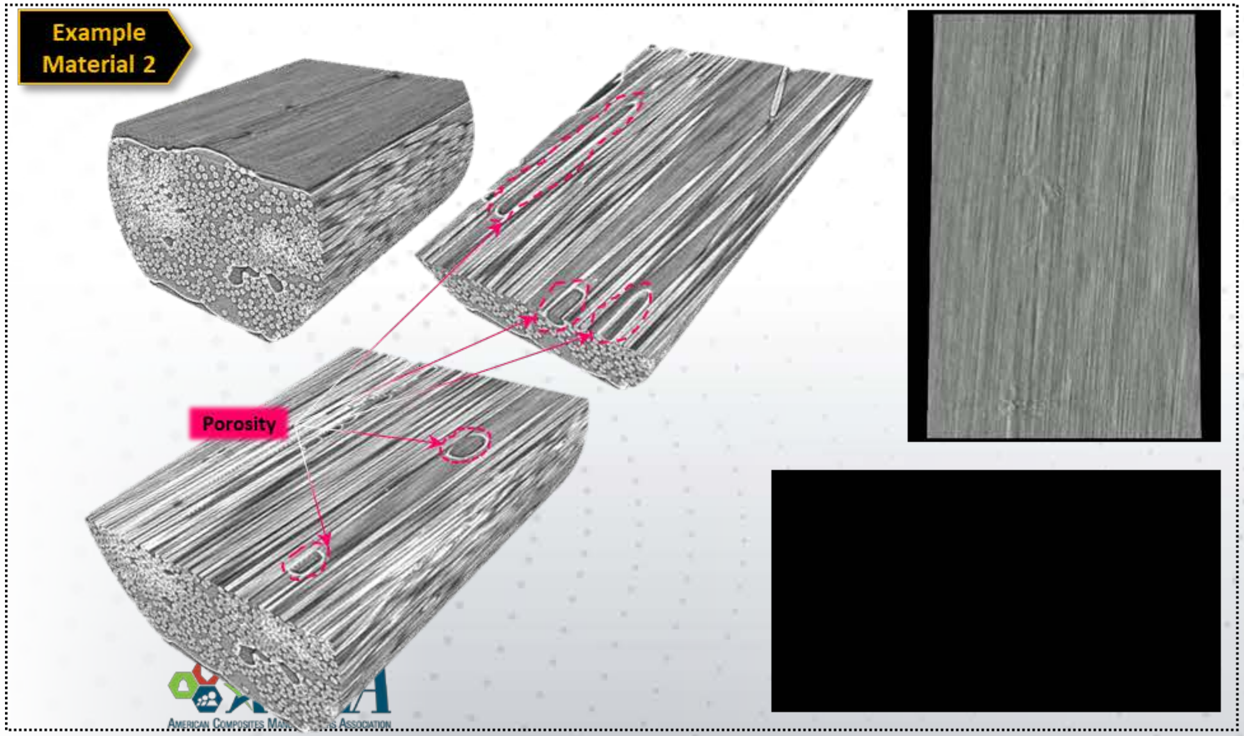
Phase IV: NCAMP Allowables & Equivalency Demonstration

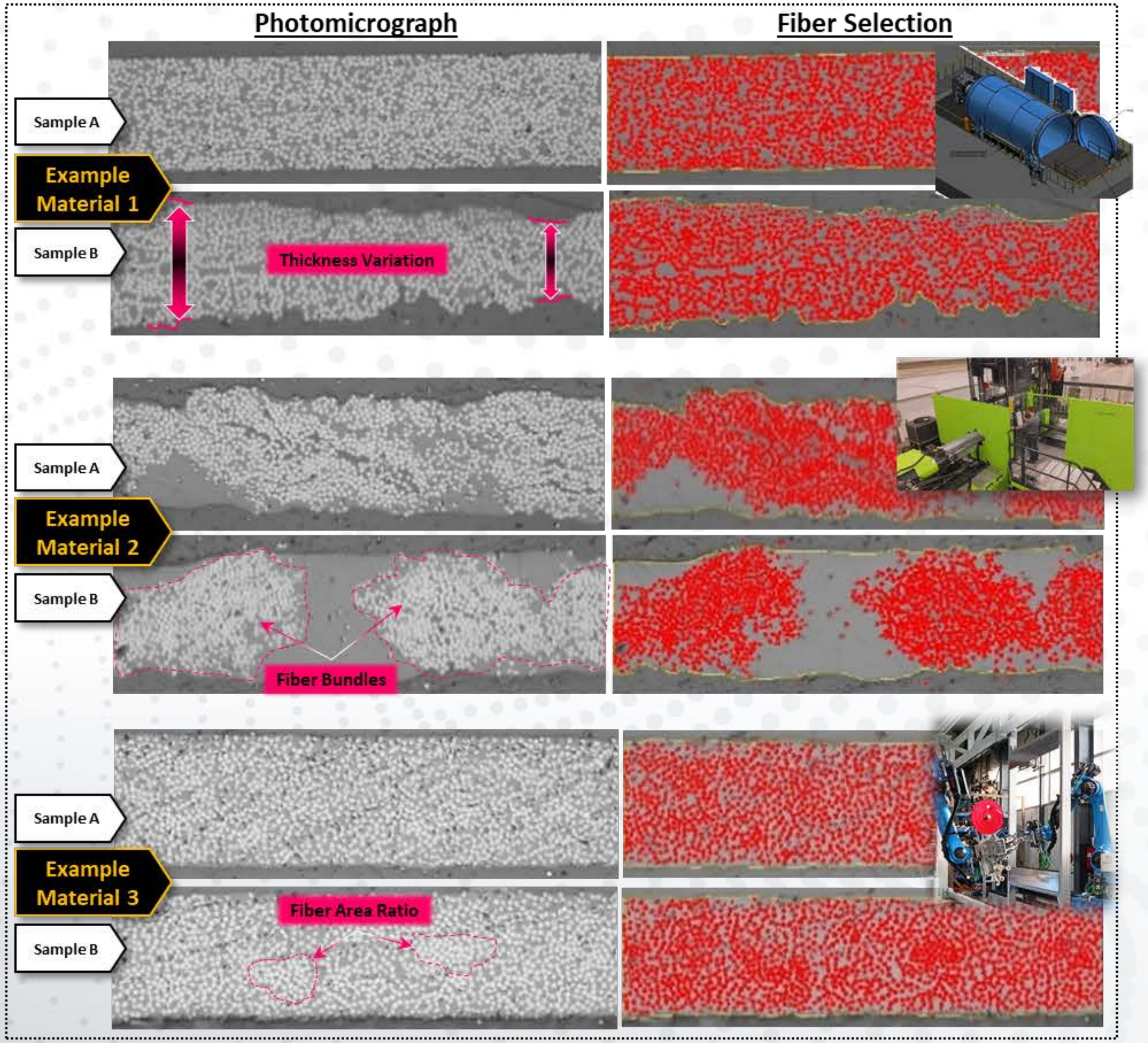


- Machine Variability
- Equivalency HL → AFP

Thermoplastic Prepreg Tape Quality

- Thermoplastic pre-impregnated tape quality variability assessment
  - TP prepreg tapes are not as evolved as thermoset prepreg tapes
  - Variability associated with TP prepreg tapes affect the AFP process and eventually the **end-product quality**
  - Past studies have shown that TP prepreg tapes can significantly vary in **thickness**, **width**, **porosity content**, and have variable **resin & fiber distributions**

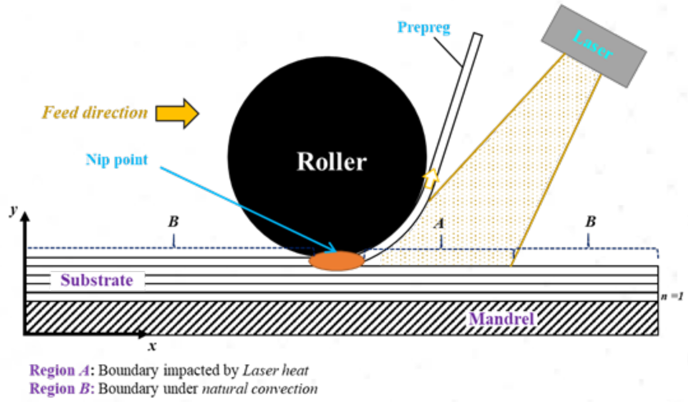




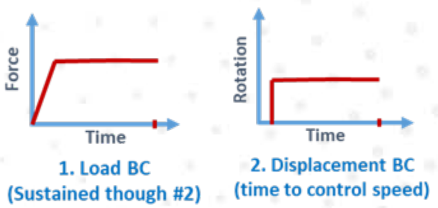
In-Situ Consolidation of Thermoplastics

AFP FEM Efforts: In-situ Consolidation Model

Prediction of residual stress & Through-thickness temperature evolution in a thermoplastic laminate fabricated by in-situ AFP process

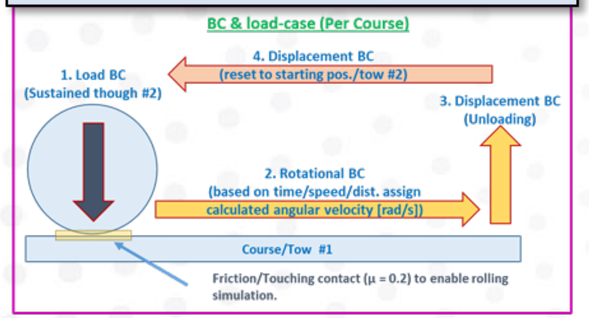


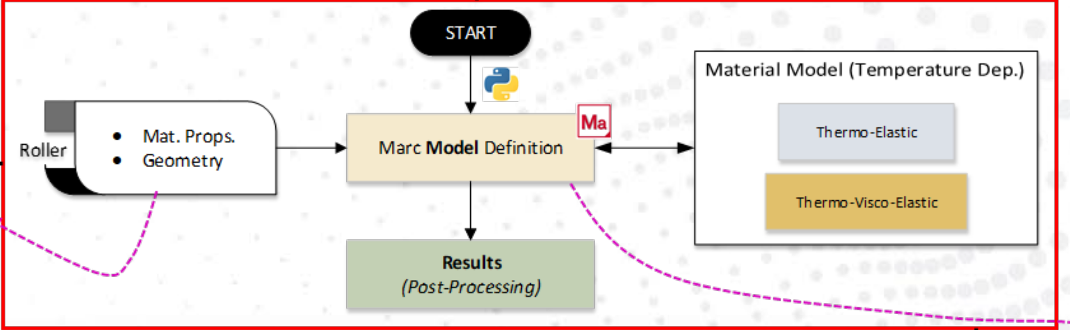
Load & Rotation modelled per course



- ***An Inverse-based Approach for Roller Mat. Props.*** *(Hyperelastic Odgen, n = 3)*
  - ***Easy to adopt any Roller type***
- ***Parametric script w/ MARC solver*** *simulates placement of each course/ply*
  - ***PY-based parametric script; Ply mat props. Roller & part geom., Roller velocity, consolidation pressure etc.***
- ***Material Model:*** *Temp. dependent Thermo-elastic material model*

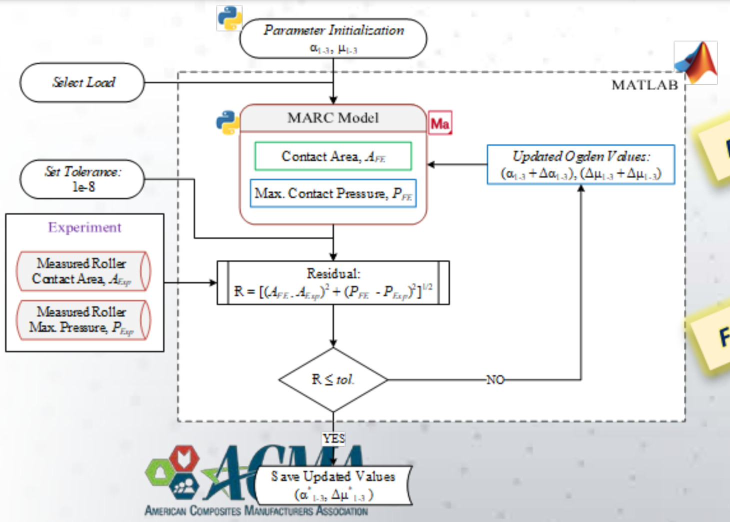
BCs & Load-case (Course/Ply Placement)

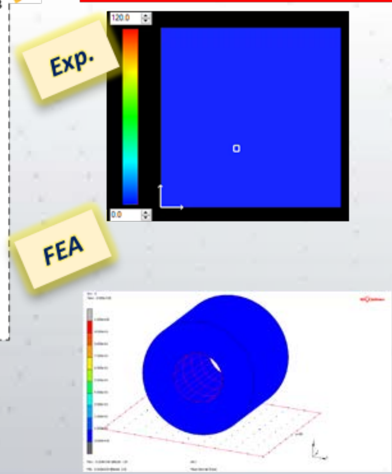




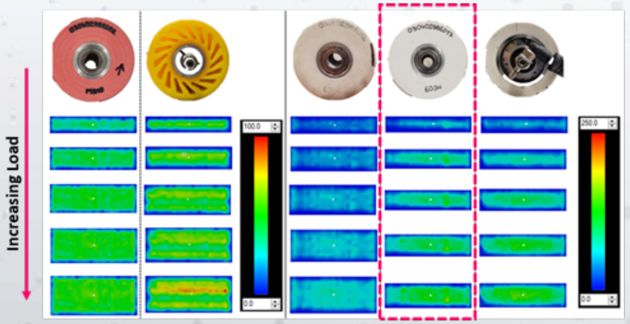
Multi-scale Parametric Model (PY-based script)

Roller Mat Prop: An Inverse Approach based Optimization

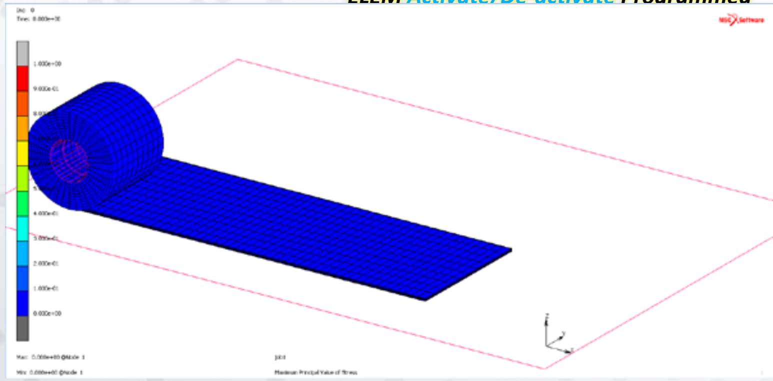




Experimental Measured Contact Area



*****ELEM Activate/De-activate Programmed***



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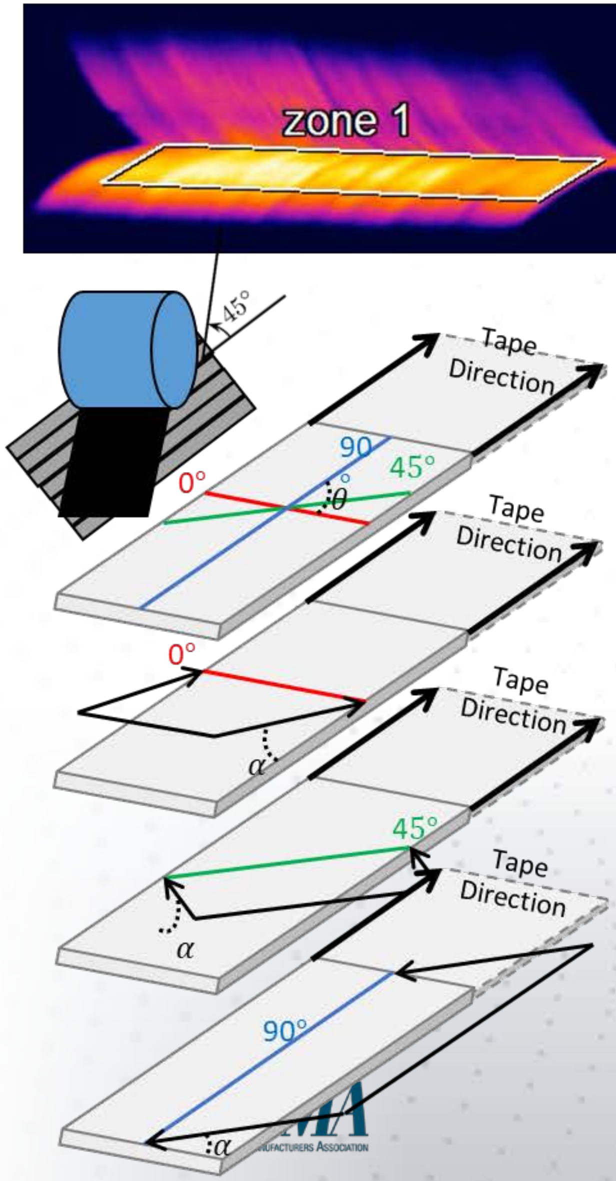
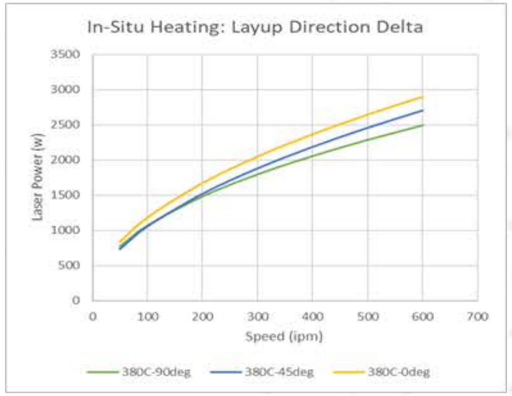
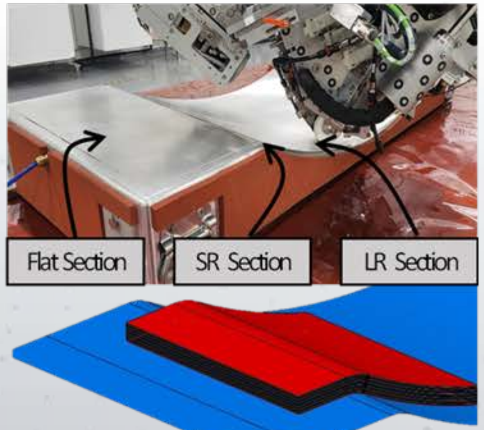
AFP Curved Panels with Heated Tooling

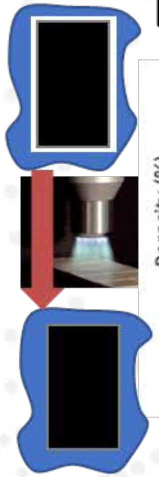


Established high-fidelity in-situ heating methods.

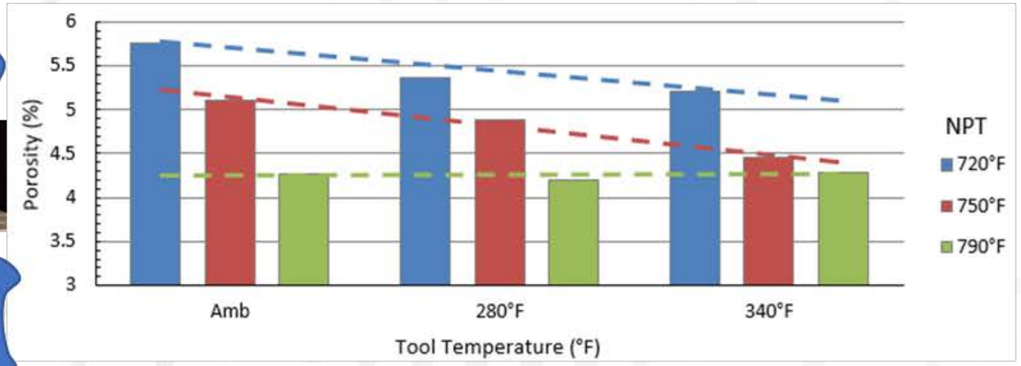


Achieved excellent quality consolidation on flat and high curvature representative parts.





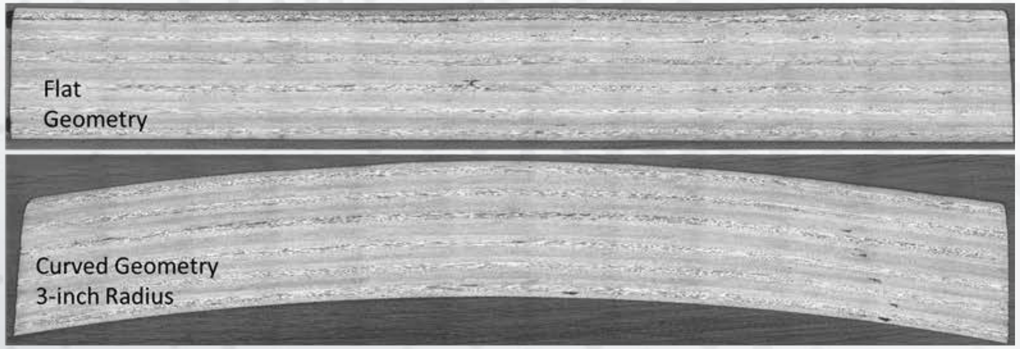
Established NPT and Tool Temperature trends



- Increased NPT decreases porosity
- Increased tool temperature decreases porosity
- 790°F (420°C) NPT local optima
- Optical analysis -> 0.3% porosity maximum

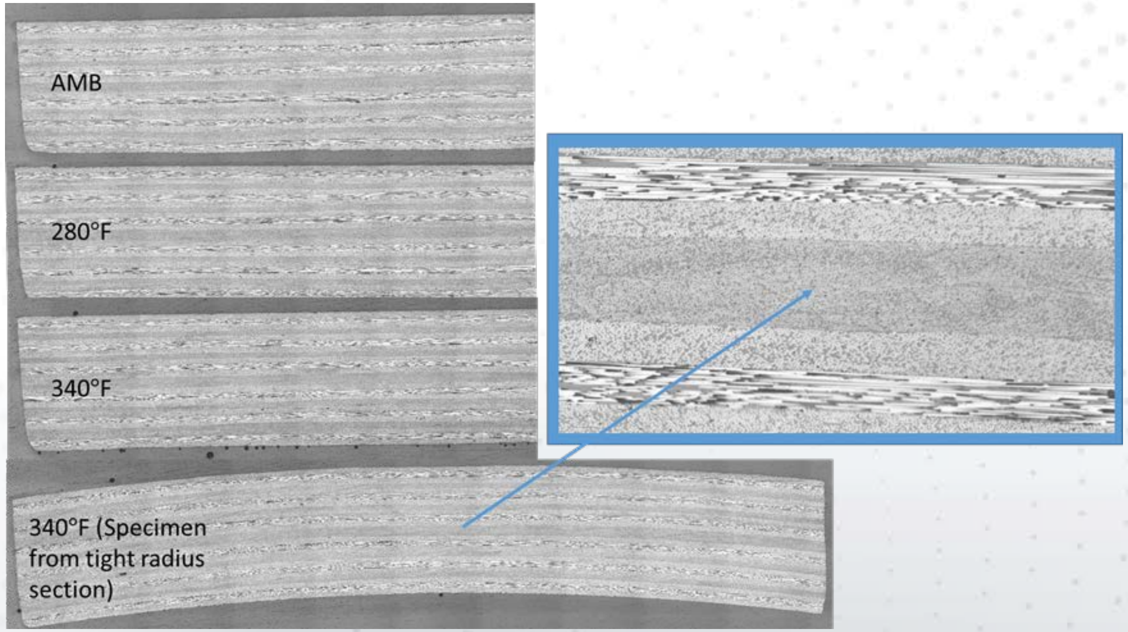
0.24% Porosity

0.11% Porosity

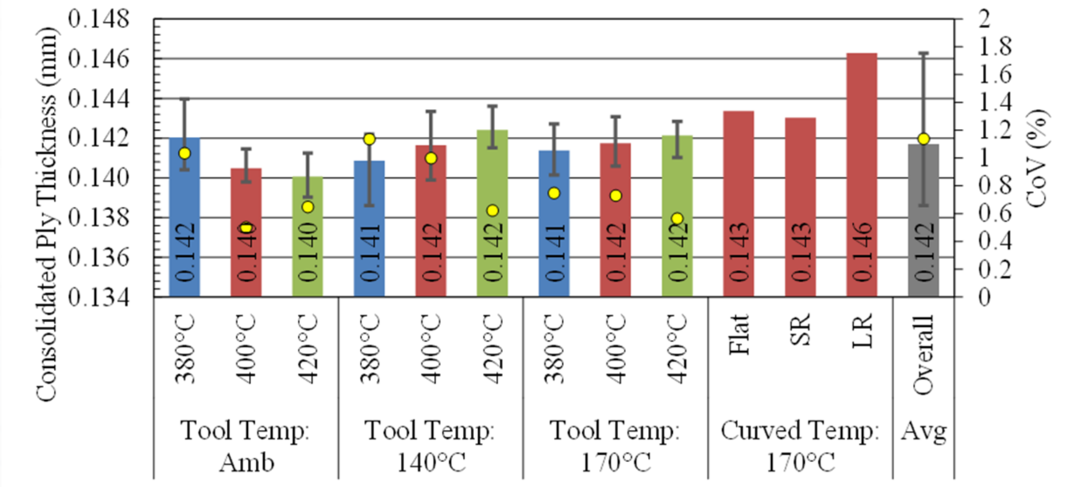


In-Situ Consolidation Quality: Photomicrographs

- **<u>Quality</u>**
  - Excellent consolidation quality
  - High curvature section shows good interface between layers

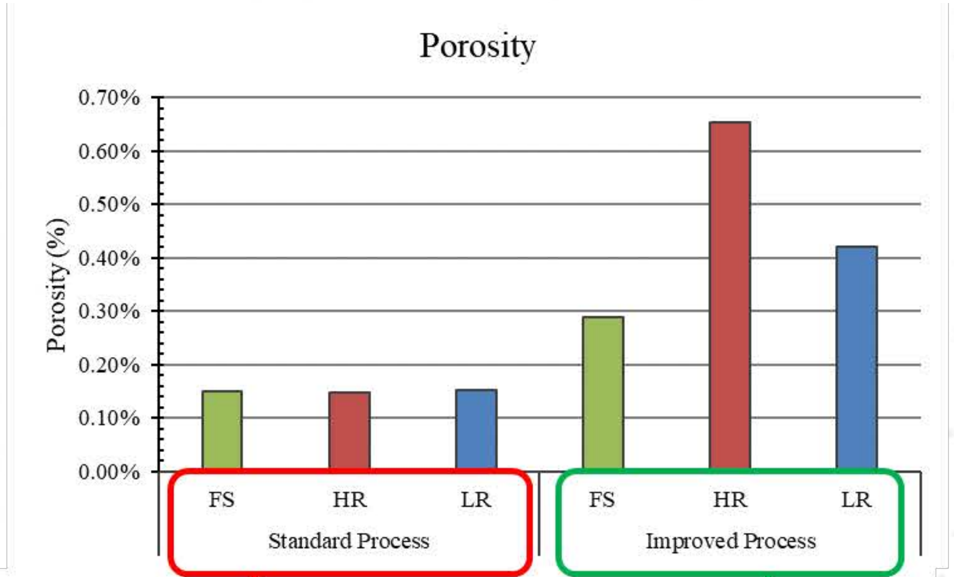


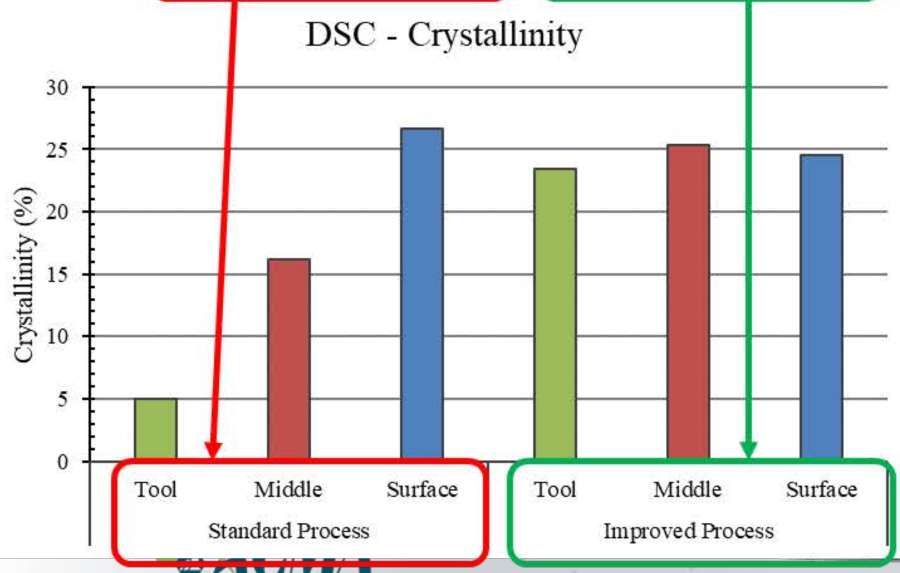
- **<u>Comparison to alternatives</u>**
  - In-Situ CPT - 0.0055in.
  - Oven CPT - 0.0054in.
  - Press CPT - 0.0051in.
  - High curvature section shows good interface between layers

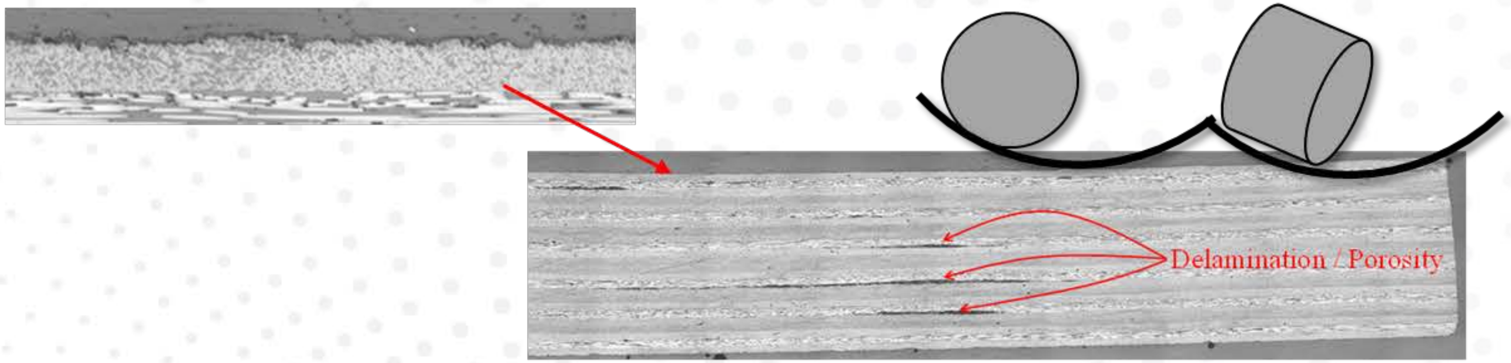


  - 8% thicker CPT than press consolidation
  - 300psi for 30 min vs 100psi for 0.2 seconds

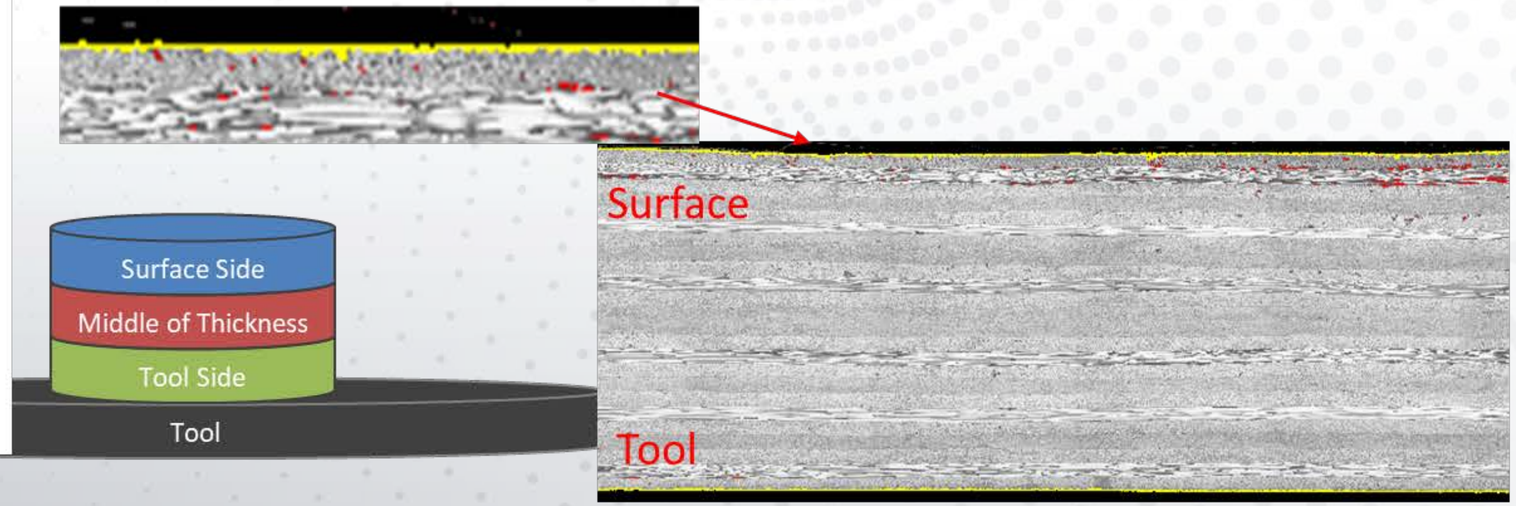
In-situ Consolidation and Secondary Heat



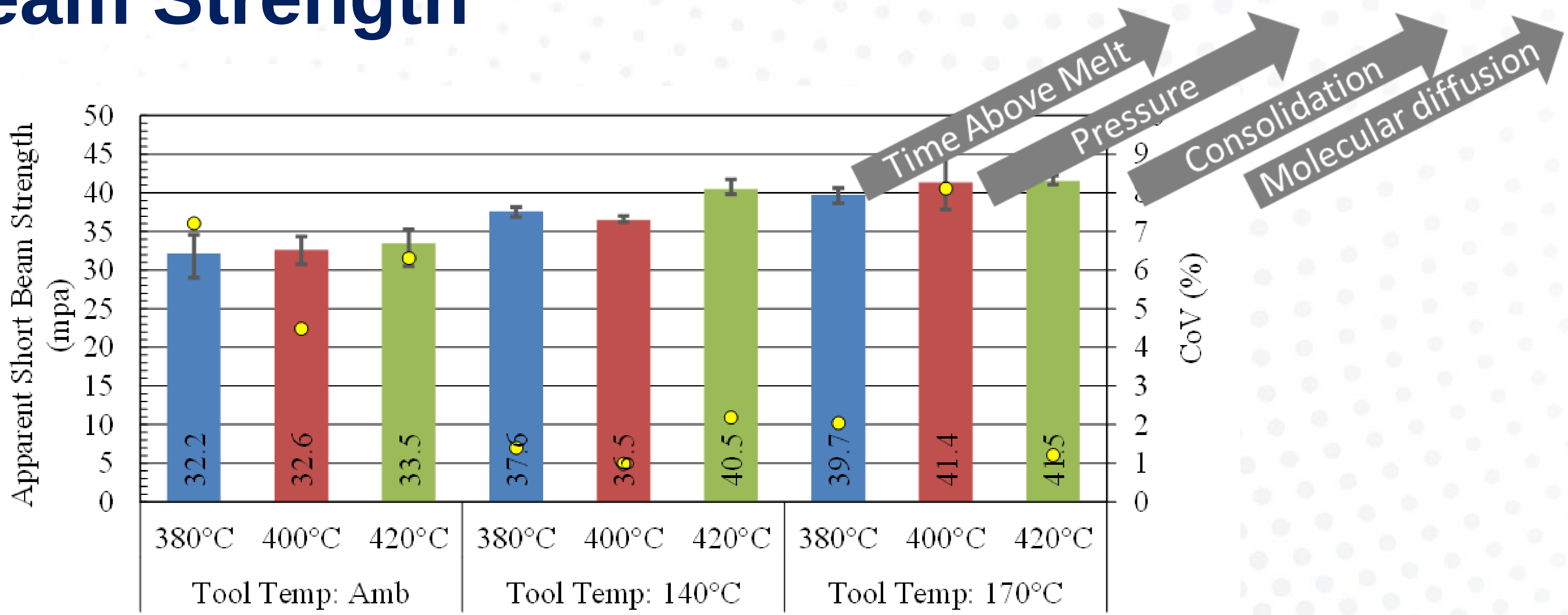




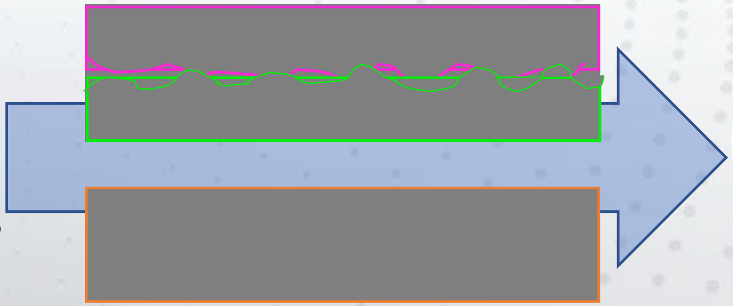
- Improved crystallinity through the thickness.
- Improved surface finish.
- Minimizes Delaminations

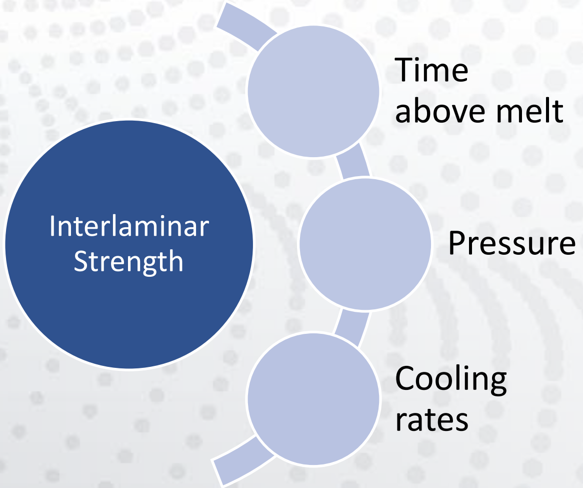


Short Beam Strength



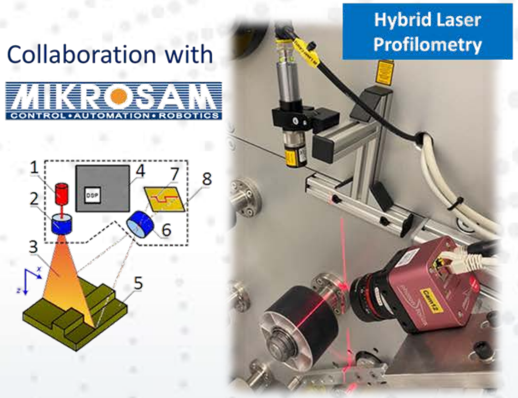
Interlaminar strength comes from molecular diffusion between plies

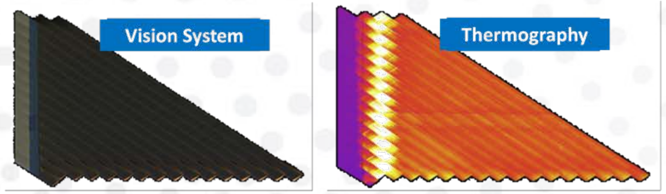


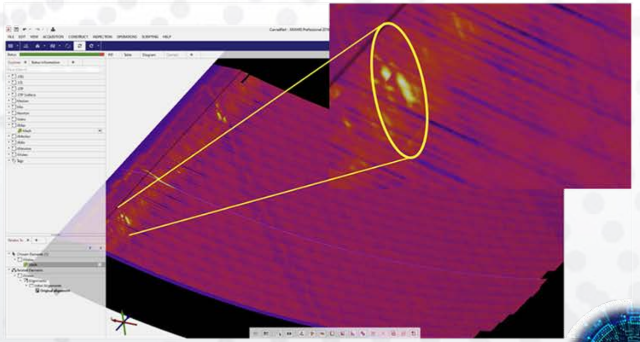


In-Process Inspections for Quality Assurance and Process Optimization

Collaboration with MIKROSAM

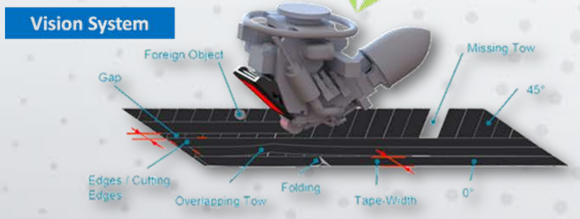




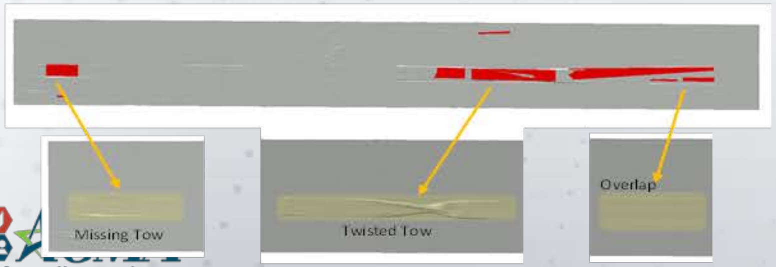


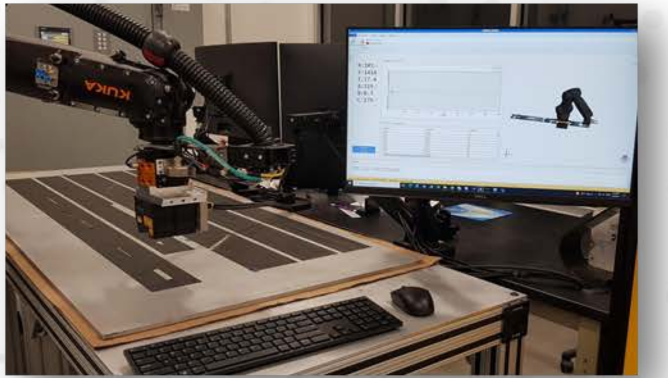
Collaboration with trilion

Collaboration with HEXAGON



In-process AFP Manufacturing Inspection System (IAMIS)



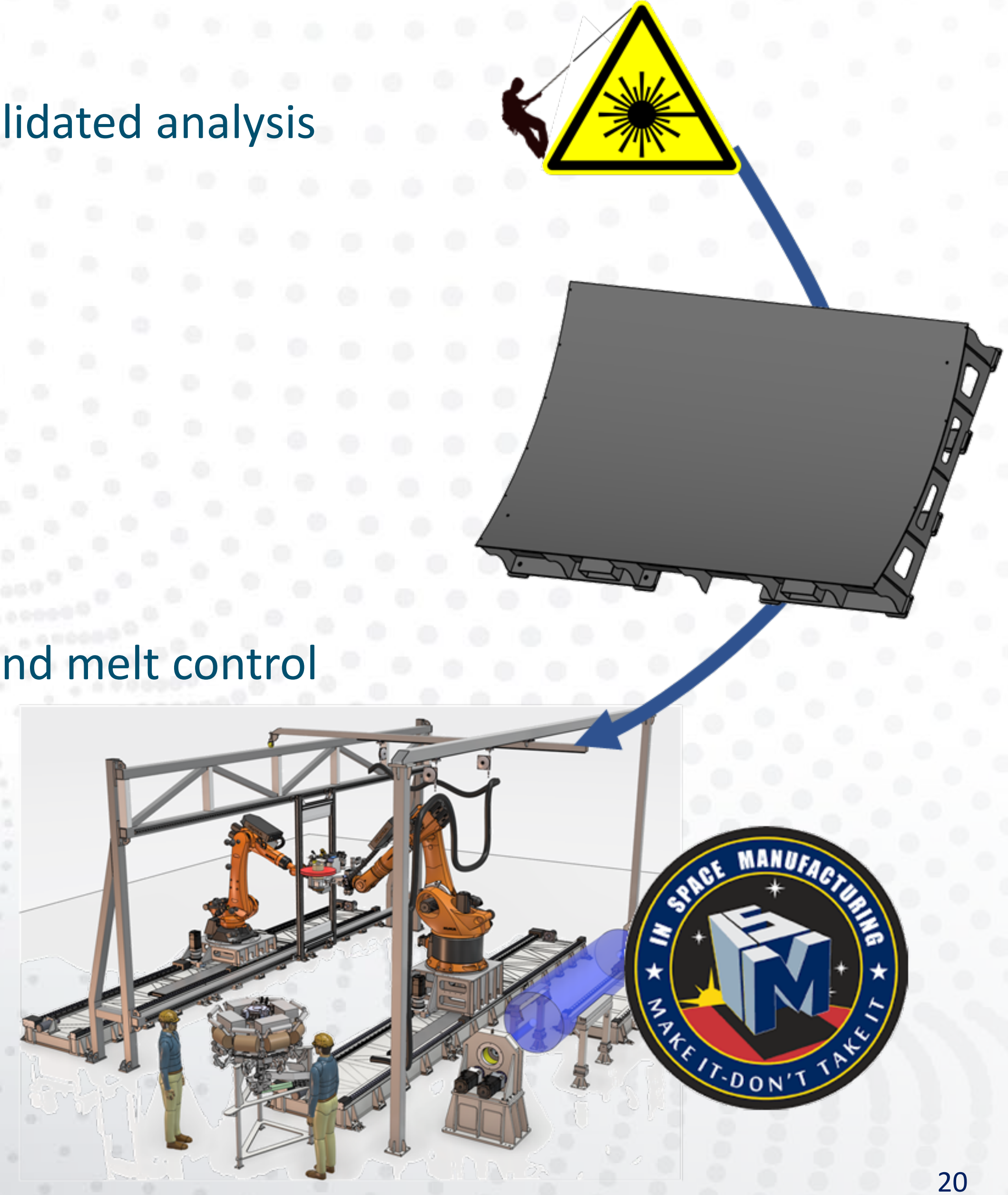


Summary

- Primary AFP parameters are highly coupled and require validated analysis for process optimization.
- ICASH process successfully produced curved fairing panels
  - 0.3% or less porosity
  - Crystallinity above 20% through the thickness

Looking Forward

- Increasing interlaminar strength via variable focus optics and melt control
- Removing the need for heated tooling on large scale parts
- Double curvature complex parts
- Completely tool-less in-situ consolidation
- In-process inspection for dimensional stability



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AFRL

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