COMPOSITES FROM IN-SITU CONSOLIDATION AUTOMATED FIBER PLACEMENT OF THERMOPLASTICS FOR HIGH-RATE AIRCRAFT MANUFACTURING

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Long Beach, CA

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Speaker Biography

- Roberto J. Cano
- NASA Langley Research Center (LaRC), Hampton, VA, USA
- Research Materials Engineer in the Advanced Material and Processing Branch of the Research Directorate
- B.S. from the University of Notre Dame (1988), Chemical Engineering
- M.S. from Clemson University (1990), Chemical Engineering
- Worked at NASA LaRC since 1990: prepreg development, composite process development, and evaluation of high-performance polymer systems

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Outline

- Hi-rate Composite Aircraft Manufacturing (HiCAM) Project
- In-situ Consolidation Automated Fiber Placement (AFP) of Thermoplastics (ICAT)
- Experimentation
  - Thermoplastic Laser Assisted AFP
  - Materials
  - Experiments
- Results
- Conclusions

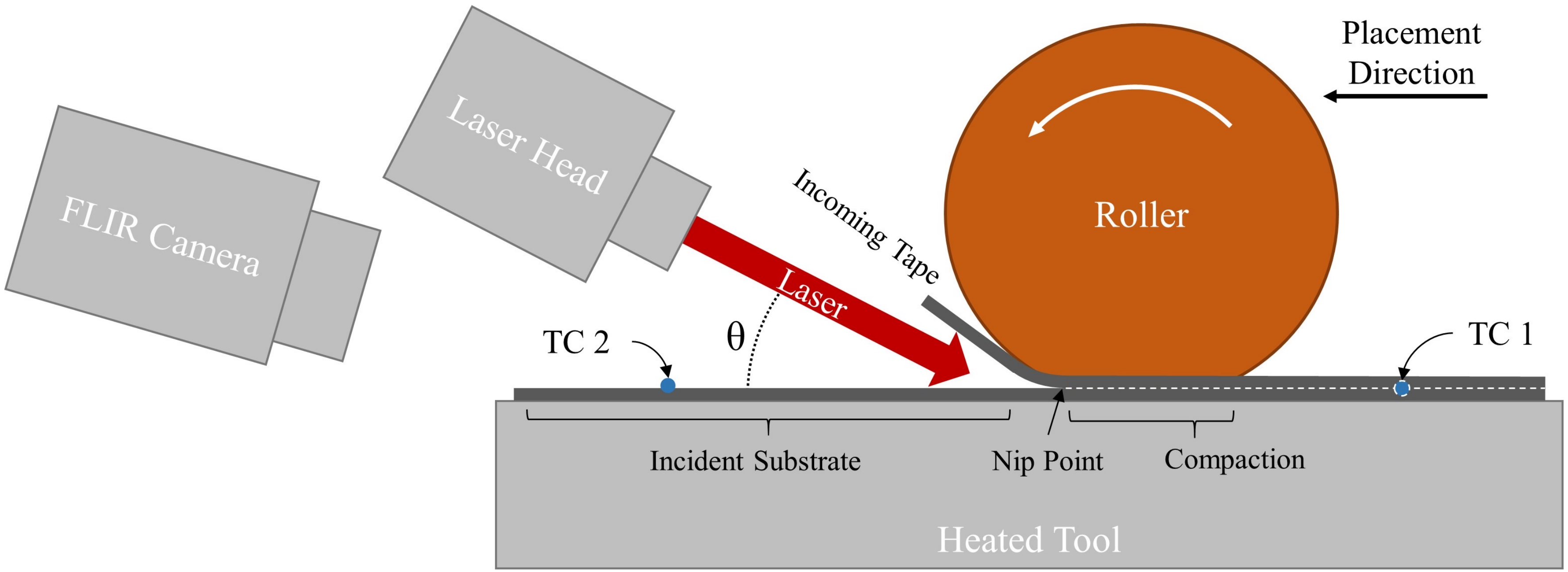
HiCAM Project

- NASA sponsored project (2021-present)
- Cost shared with industry and academic partners
- Develop rapid production of commercial airframes using composite materials
- Increase manufacturing rate by 6x the baseline (2020), up to 80 aircraft/month with reduced cost and no weight penalty
- Advance multiple technologies to technology readiness level (TRL) 6-7 by the year 2027
- Areas of focus: Next Generation Thermosets, Resin Infusion, and Thermoplastics

In-situ Consolidation AFP of Thermoplastics

- **Thermoplastics (TP) Materials**
  - suitable for rapid manufacturing due to their formability at elevated temperatures
  - comparable mechanical performance to toughened epoxy matrix composites
  - improved fracture toughness
  - high chemical and moisture resistance
  - potential for recyclability
  - eliminates the need for freezer storage
  - no material out time concerns
- **In-situ Consolidation AFP of TP (ICAT)**
  - Eliminates need for an autoclave

Schematic Diagram of Laser-assisted AFP



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Electroimpact® Six-axis AFP Robot Arm

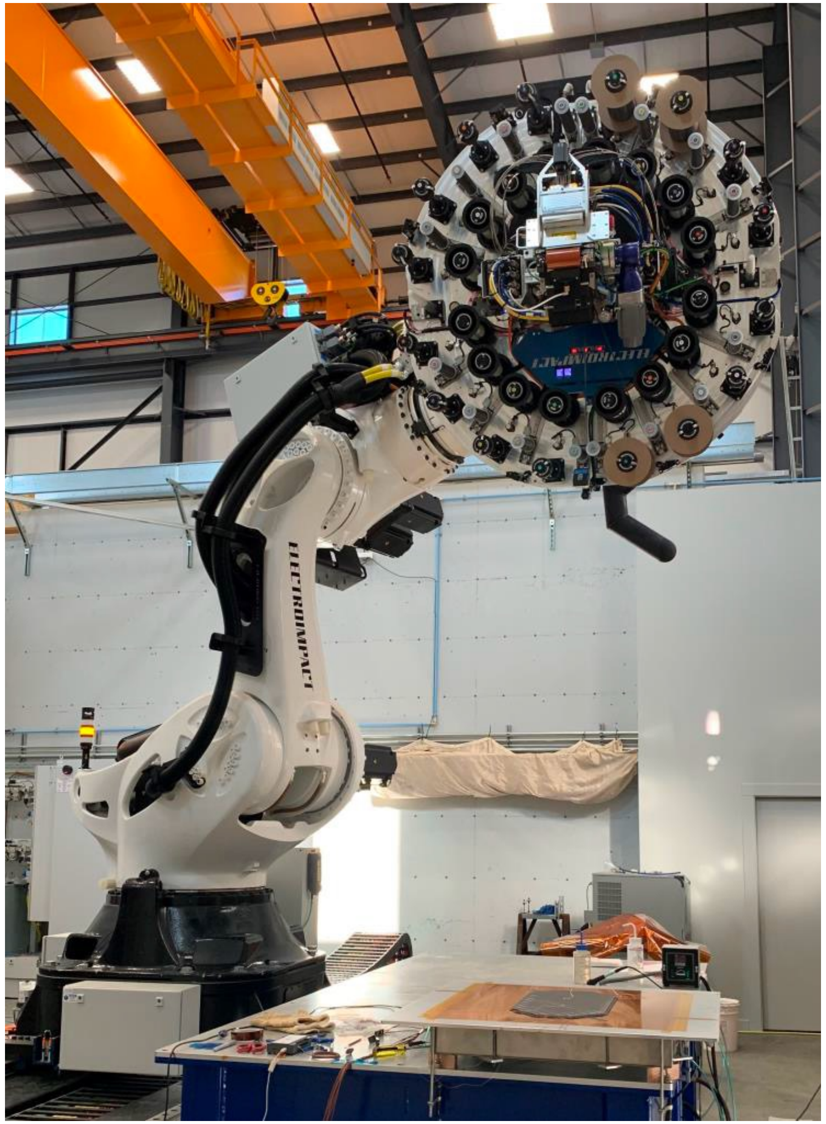

Image Credit: Electroimpact, Inc.®

- Six-axis Kuka Titan® robotic
- Electroimpact® developed Q16 placement head
- 2.54-cm wide courses: four 0.635-cm wide carbon fiber/thermoplastic matrix tapes
- Custom, 9.5-mm thick, aluminum tool heated by a hotplate supplied by Wenesco®
- Electroimpact® 400 W per lane, 976-nm wavelength, VSSL-HP (Variable Spot Size Laser-High Power)
  - one for each tow
  - controlled individually

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Thermoplastic Slit Tape Material Thermal Properties

Thermoplastic Tape	Supplier	Trade Name	Fiber Areal Weight, gsm	Polymer T_g, °C	Polymer T_m, °C (Resin/Composite)	2 wt% Decomposition Temperature, °C (Resin/Composite)
T800/PEEK	Toray	Cetex® TC1200	145	145	362/359	525/556
IM7/LM-PAEK	Victrex	AE™250	145	151	332/329	510/557
IM7/PEKK	Hexcel	Hexply-Kepstan® PEKK	190	157	354/358	537/555

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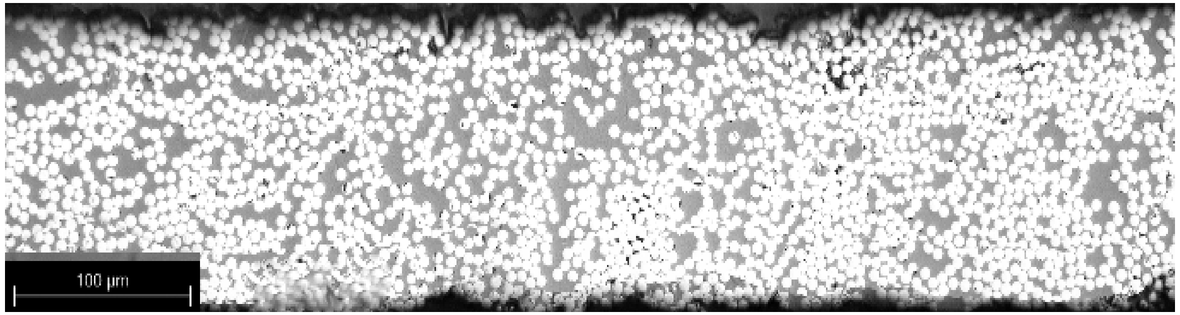
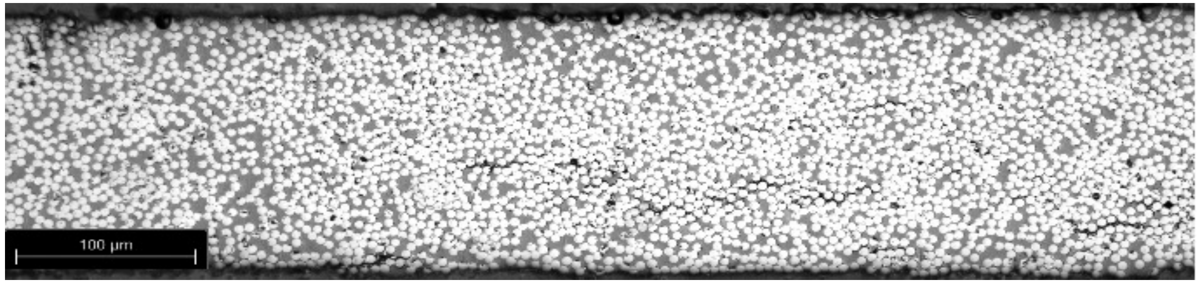
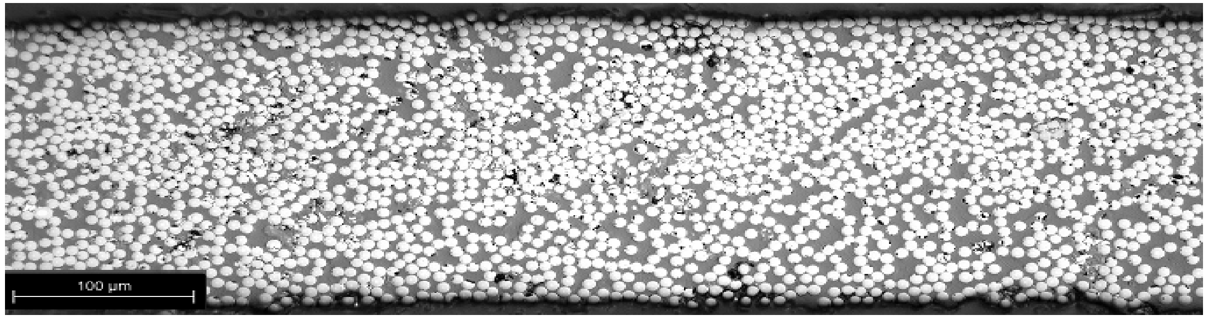
Thermoplastic Slit Tape Photomicrographs



Toray T800/PEEK



Victrex IM7/LM-PAEK



Hexcel IM7/PEKK

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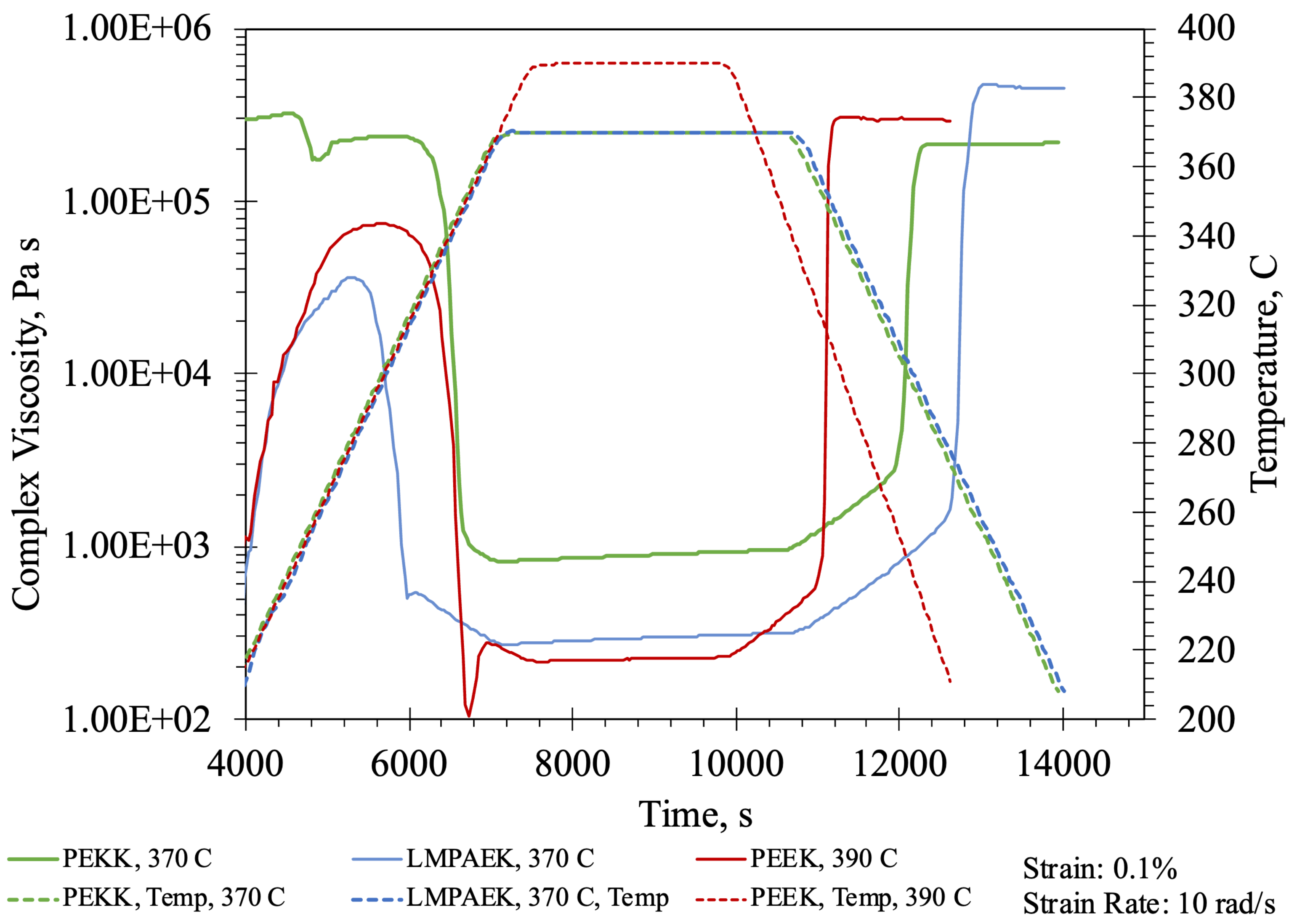
Parallel Plate Rheology of PEEK, LM-PAEK, and PEKK



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[**PEKK:** Kepstan polyetherketoneketone, **PEEK**: TC1200 polyetheretherketone, **LM-PAEK**: Victrex low-melt polyaryletherketone]

Panel Fabrication Parameters

Panel	Layup Speed (V), mm/s	Average Laser Power, W	Tool Temperature (TT), °C	Target Peak Surface Temperature (ST), °C
T800/PEEK	100	185	120	500
IM7/LM-PAEK	400	365	80	450
IM7/PEKK-A	25	61	180	525
IM7/PEKK-B	50	89	180	525
IM7/PEKK-C	100	133	200	550

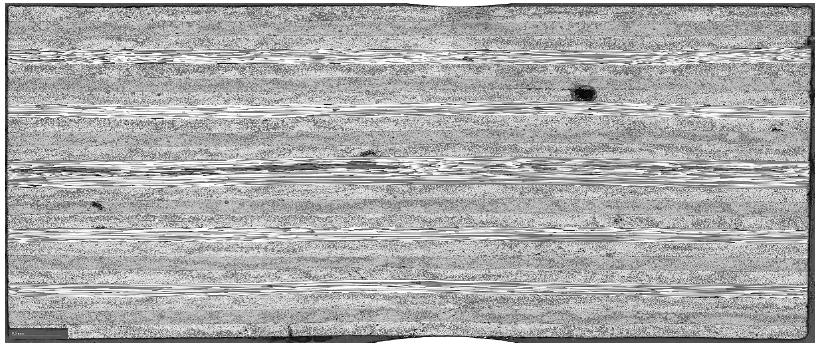
Post ICAT Panel Fabrication Procedures

AFP fabricated 25.4 cm x 50.8 cm $[45/0/-45/90]_{3S}$ panels were machined into three sections:

- **"ICAT-only"** panel
- **"ICAT + vacuum-bag-oven (VBO)"** post-consolidation panel
    - post-processed under a vacuum bag in an oven
- **"ICAT + autoclave"** post-consolidation panel
    - post processed in autoclave at elevated temperature and pressure

Post processing utilized vendor recommended temperature and pressure cycles.

Photomicrographs

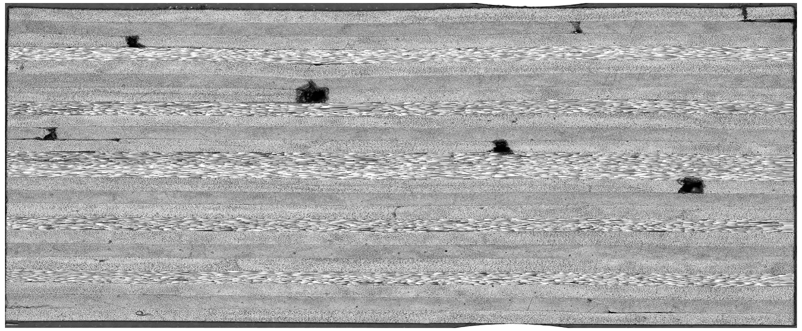


ICAT-only

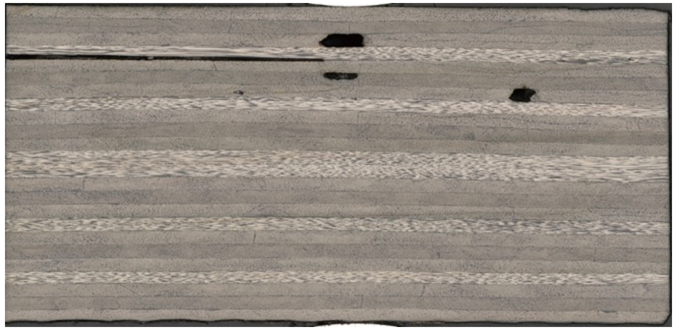
ICAT+VBO

ICAT+autoclave

T800/PEEK Panel (ST = 500°C, TT = 120°C, V = 100 mm/s)



ICAT-only

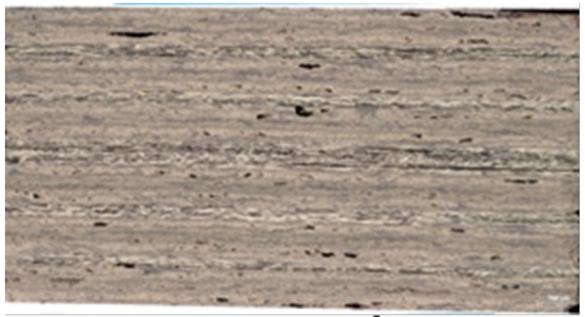


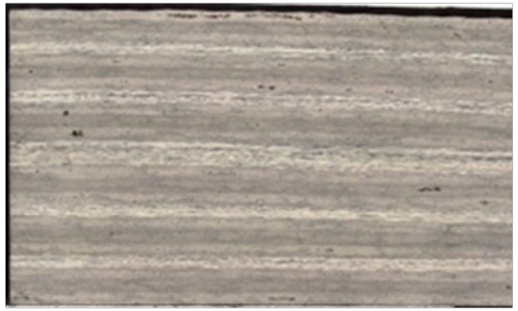
ICAT+VBO

ICAT+autoclave

IM7/LM-PAEK Panel (ST = 450°C, TT = 80°C, V = 400 mm/s)

Photomicrographs

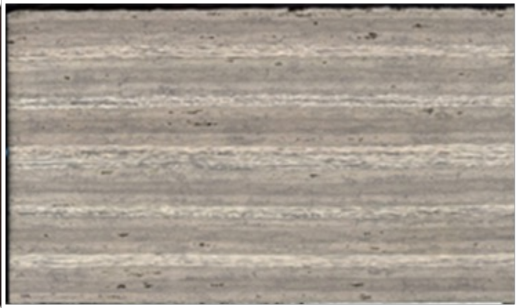

ICAT-only


ICAT+VBO


ICAT+autoclave

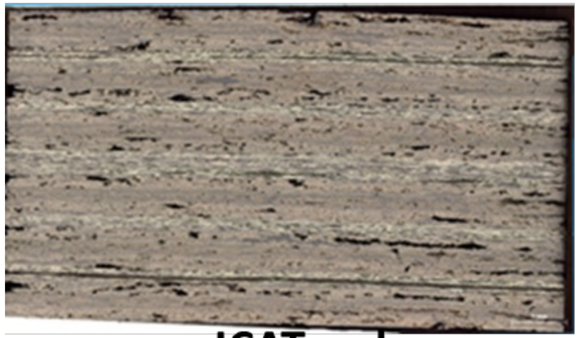
IM7/PEKK Panel A (ST = 525°C, TT = 180°C, V = 25 mm/s).


ICAT-only


ICAT+VBO


ICAT+autoclave

IM7/PEKK Panel B (ST = 525°C, TT = 180°C, V = 50 mm/s).

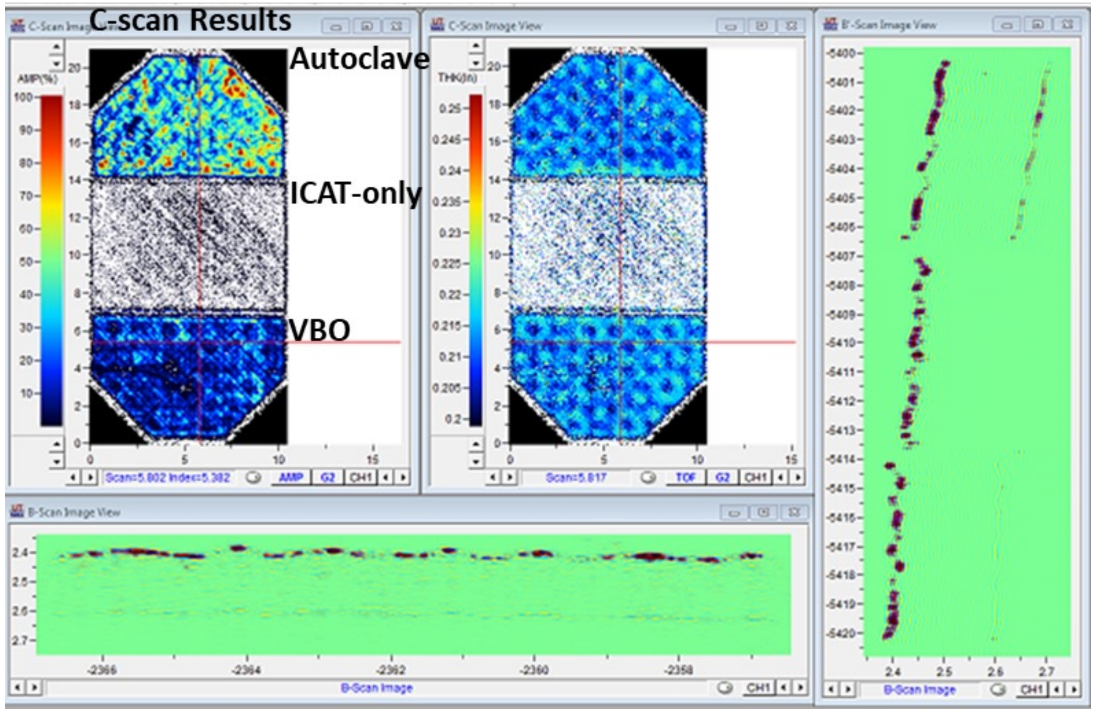

ICAT-only


ICAT+VBO

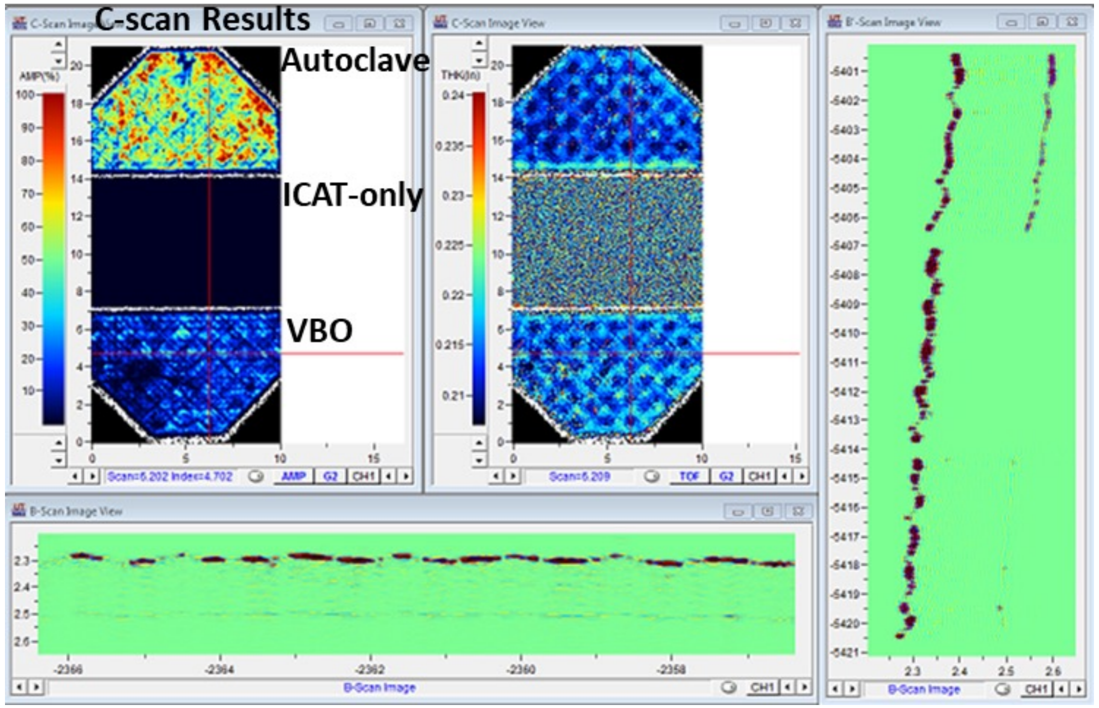

ICAT+autoclave

IM7/PEKK Panel C (ST = 550°C, TT = 200°C, V = 100 mm/s).

Nondestructive Inspection (NDI) Results



IM7/PEKK Panel A (ST = 525°C, TT = 180°C, V = 25 mm/s)



IM7/PEKK Panel B (ST = 525°C, TT = 180°C, V = 50 mm/s)

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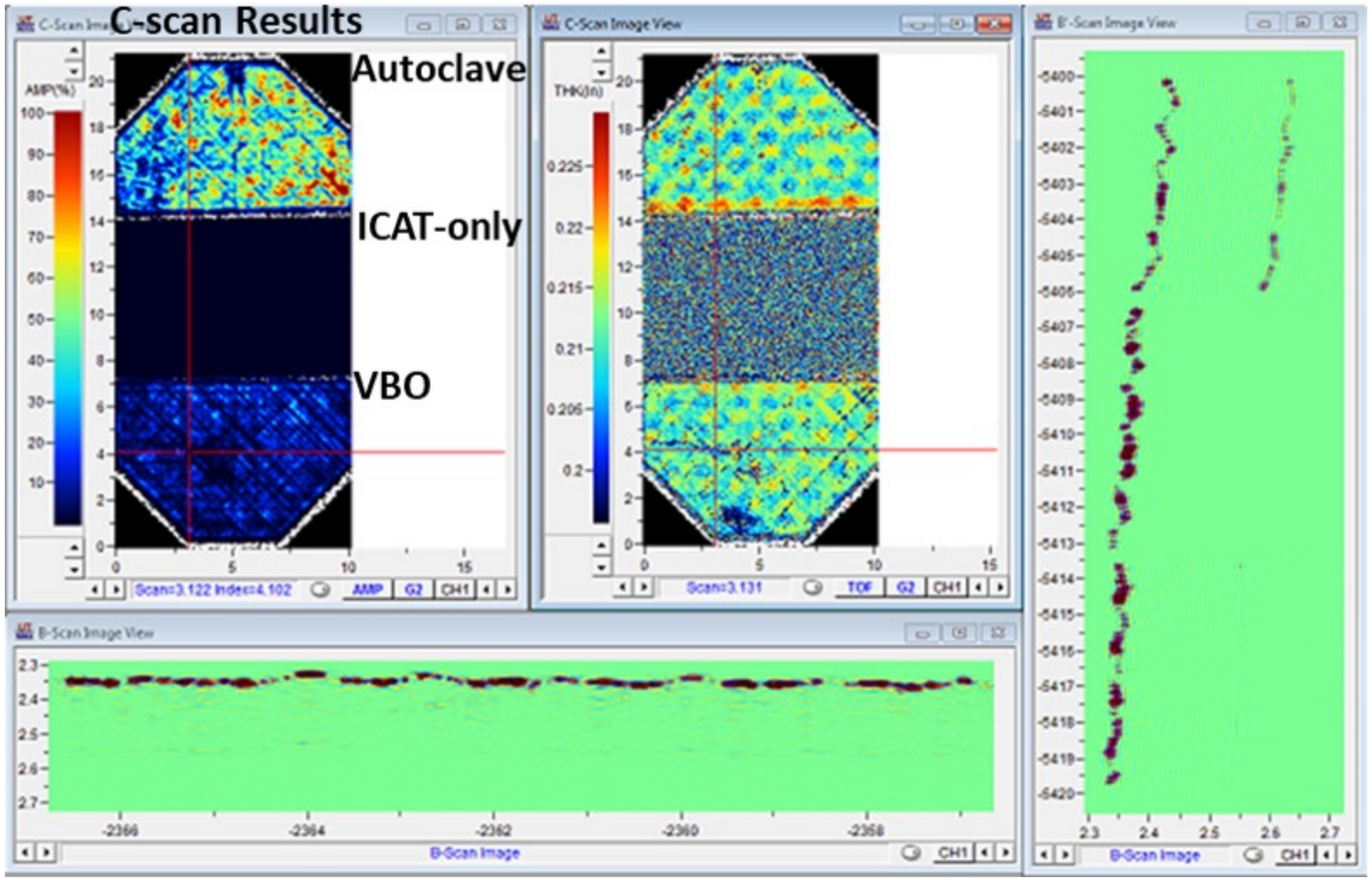
NDI Results



IM7/PEKK Panel C (ST = 550°C, TT = 200°C, V = 100 mm/s)

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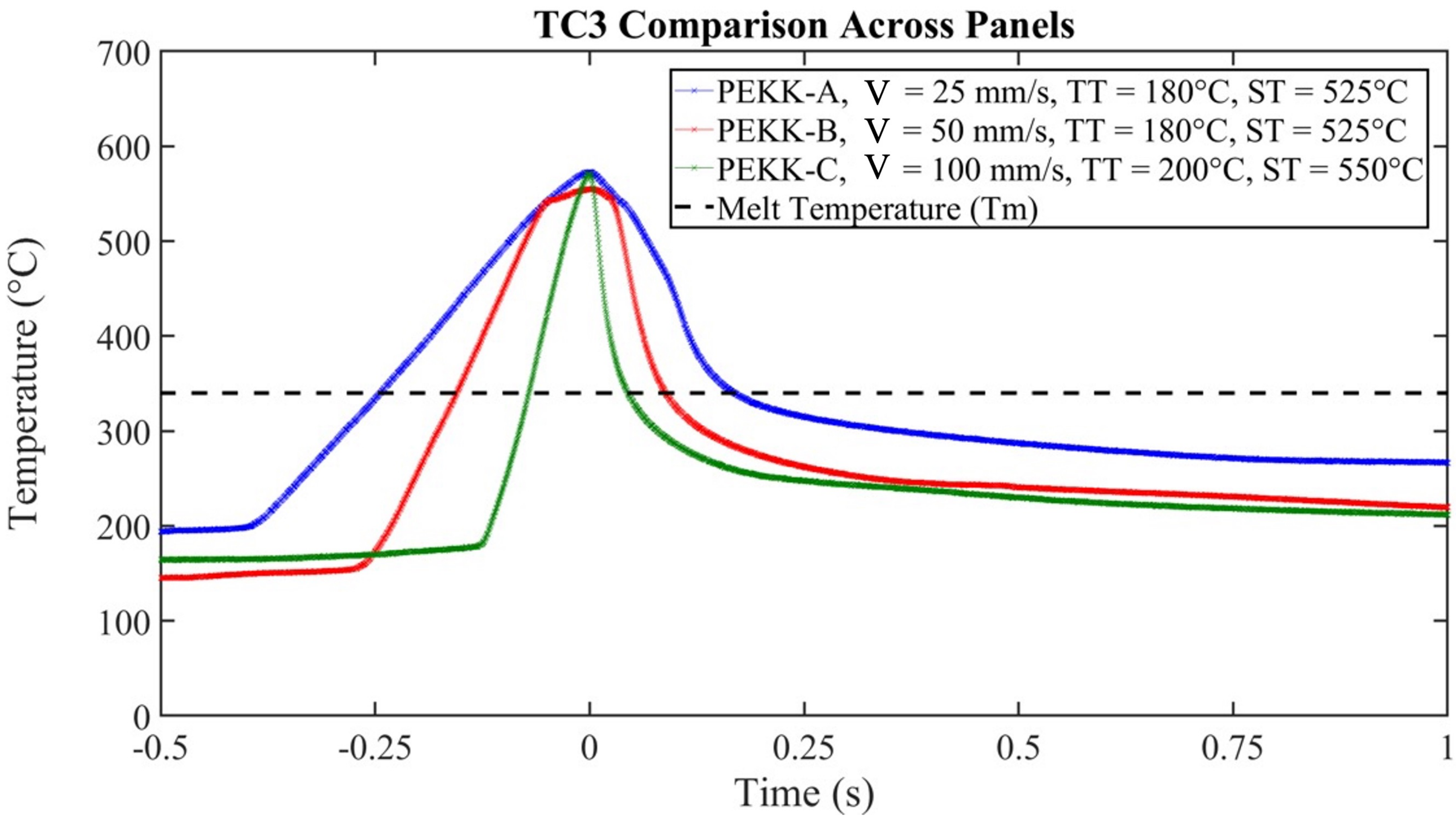
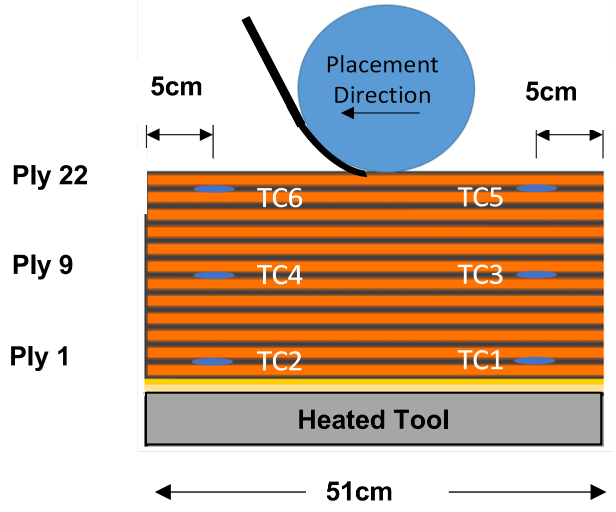
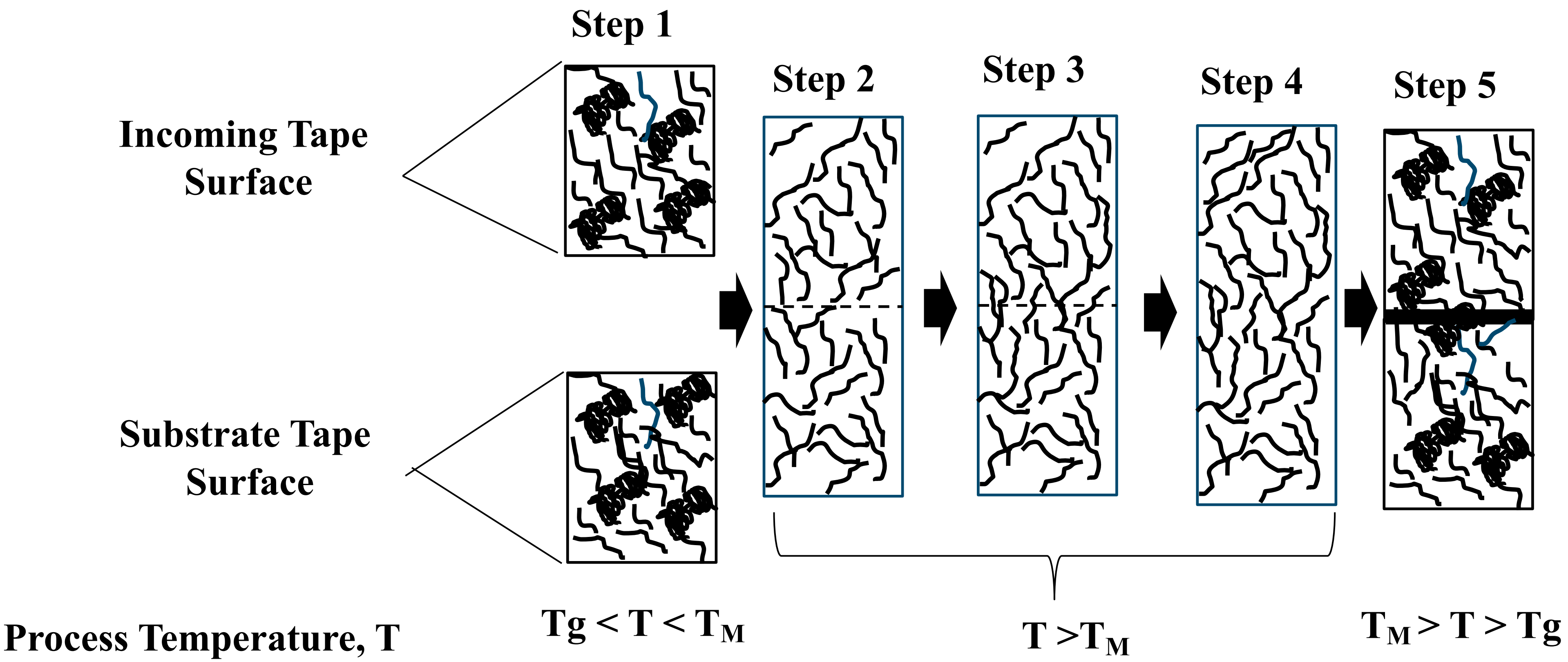
Thermal Measurements During AFP

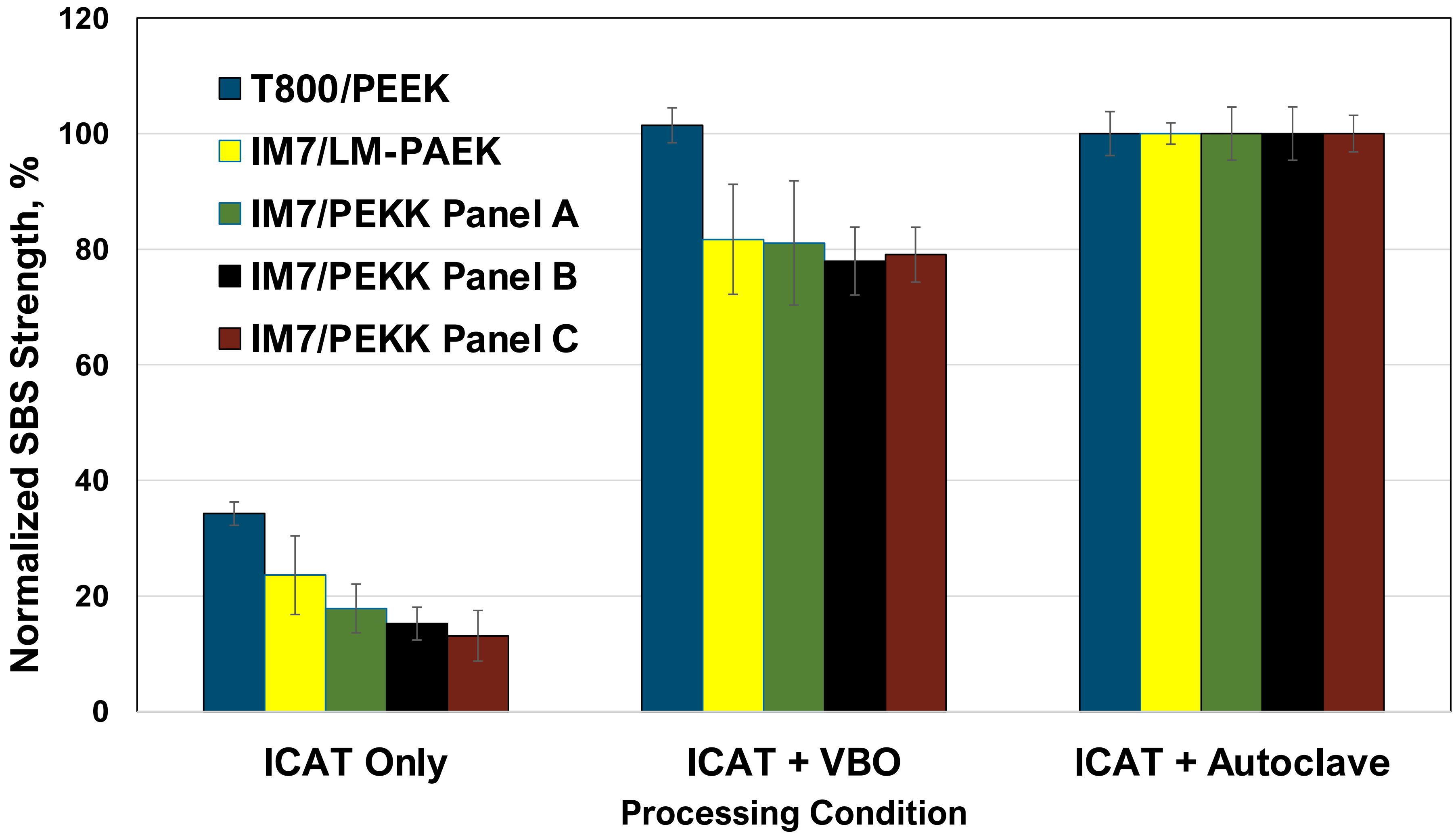




Thermoplastic Auto-hesion



Short Beam Shear (SBS) Results



Normalized to the “ICAT + Autoclave” values

Conclusions

- Evaluated ICAT process using state-of-the-art (SoA) AFP equipment with a diode laser heating system
  - T800/PEEK, IM7/LM-PAEK, and IM7/PEKK
- Five 24-ply, quasi-isotropic laminates fabricated
  - laser target temperatures ranging from 450°C to 525°C
  - heated tool temperatures ranging from 80°C to 180°C
  - placement speeds ranging from 25 mm/s (59 in./min) to 400 mm/s (950 in./min)
- SBS values of “ICAT-only” less than 40% of the average SBS of ICAT panels consolidated in the autoclave after placement
- The ICAT process using current SoA equipment does not appear to be a viable process for high-rate production of primary composite structures on aircraft without hardware modifications to increase time above melt temperature
- High-rate thermoplastic AFP plus VBO processing offers attractive compromise

HiCAM Future Work

- Optimize thermoplastic high-speed AFP process followed by an out-of-the-autoclave VBO process to potentially meet future aircraft production needs and HICAM goals.

Questions?

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