HIGH-RATE AUTOMATED FIBER PLACEMENT FOLLOWED BY VACUUM BAG ONLY CONSOLIDATION OF SEMI-CRYSTALLINE THERMOPLASTIC COMPOSITES

Presented By:
Dr. Tyler B. Hudson
Senior Materials Research Engineer
NASA Langley Research Center
Hampton, VA 23681, USA

sampe
Conference & Exhibition
2025
Indianapolis, IN

Speaker Biography

Dr. Tyler Hudson is a Senior Materials Research Engineer at NASA Langley Research Center. He began his career at NASA Langley Research Center in 2014 as a Graduate Research Assistant with the National Institute of Aerospace (NIA). He received his Ph.D. in Aerospace Engineering from North Carolina State University in 2017. His research has focused on manufacturing and process monitoring of advanced aerospace composite structures. He has made significant technical contributions to NASA projects within the Aeronautics Research Mission Directorate and Space Technology Mission Directorate. He has earned numerous accolades including the NASA Early Career Achievement Medal, Young Engineer of the Year Awards from the Hampton Roads Section of AIAA and the Peninsula Engineers Council (PEC), the Inside Business Top 40 Under 40, and the Outstanding Young Alumni Award from the Mechanical and Aerospace Department of N.C. State. He is also active as a volunteer and leader in his community.

sampe North America

HIGH-RATE AUTOMATED FIBER PLACEMENT FOLLOWED BY VACUUM BAG ONLY CONSOLIDATION OF SEMI-CRYSTALLINE THERMOPLASTIC COMPOSITES

Tyler B. Hudson[1], Brian W. Grimsley[1], Roberto J. Cano[1], Jin Ho Kang[1], Rodolfo Ledesma[2], Ryan F. Jordan[3], Ryan Eldridge[3], Thammaia Sreekantamurthy[2], and Jamie C. Shiflett[4]

[1]NASA Langley Research Center, Hampton, VA 23681
[2]Analytical Mechanics Associates, Inc., Hampton, VA 23681
[3]Electroimpact, Inc., Mukilteo, WA 98175
[4]Science and Technology Corporation, Hampton, VA 23666

SAMPE Conference and Exhibition
Indianapolis, IN
May 19-22, 2025

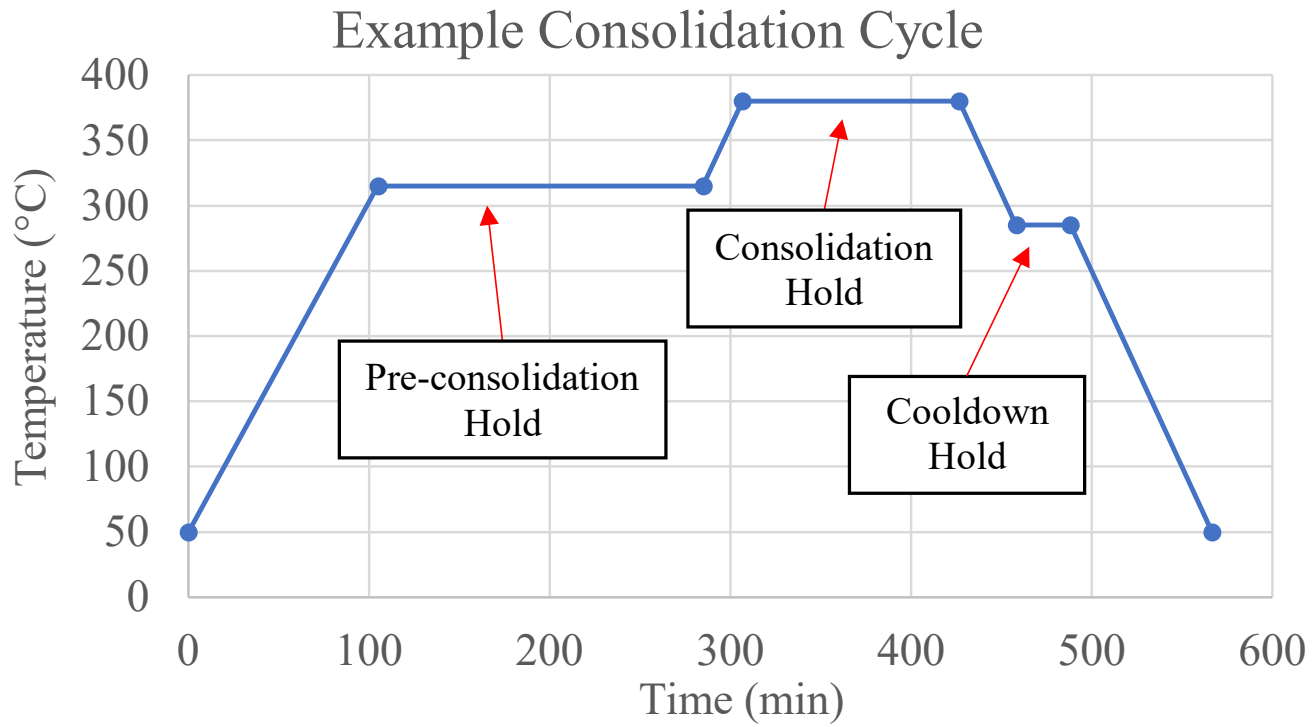
Introduction

- Hi-rate Composites Aircraft Manufacturing (HiCAM) project
  - Objective: 4-6X increase in composites primary structure manufacturing rate with no weight or cost penalty
- Semi-crystalline polyaryletherketone (PAEK) thermoplastic composites are an attractive rate enabling material
  - Higher mode-I fracture toughness ≈2.1 kJ/m^2 (12 in.-lb./in.^{2})† than toughened epoxies
  - Indefinite "out times" eliminate freezer storage requirement
  - Autohesion phenomena results in fully healed, or welded plies in short times compared to the 6+ hour autoclave "cure" cycle requirement of thermoset composites
- Out-of-autoclave (OoA), vacuum bag oven (VBO) consolidation of thermoplastic composites
  - Reduces processing expenses by eliminating the high cost of an autoclave
  - Thermoplastics can be processed faster than thermosets

†Toray "Cetex® TC1225 Product Data Sheet," https://www.toraytac.com/product-explorer/products/gXuK/Toray-Cetex-TC1225

VBO Panel Variable Overview

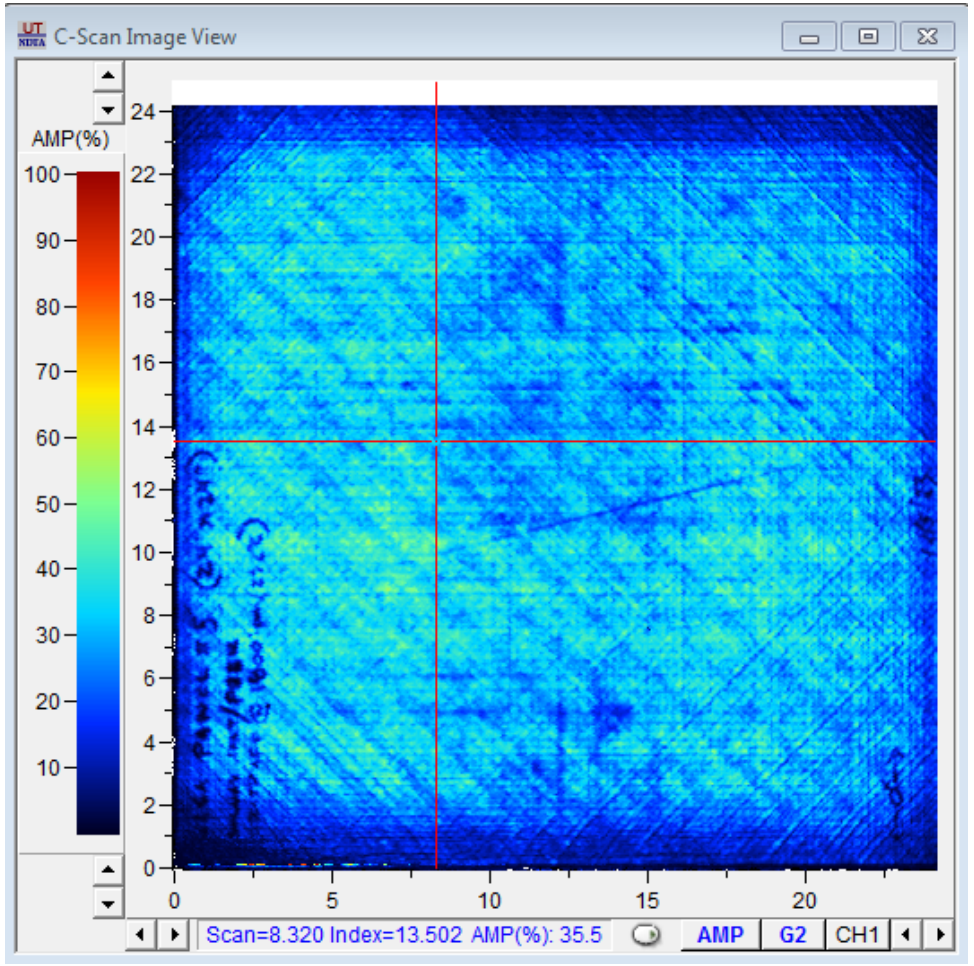
- 2 Materials: IM7/PEKK, Solvay (now Syensqo) IM7/PEEK
- 1 Layup: Quasi-isotropic $[45/90/-45/0]_{4S}$
- 2 Automated Fiber Placement (AFP) Speeds: 423, 762 mm/s
- 4 Consolidation Hold Times: 5, 60, 120, 180 min
- 2 Consolidation Hold Temperatures: 380°C (IM7/PEKK) and 390°C (IM7/PEEK)
- 3 Pre-consolidation Hold Options:
  - 315°C for 180 min (IM7/PEKK)
  - 320°C for 180 min (IM7/PEEK)
  - No Pre-consolidation Hold Step
- 3 Cooldown Hold Options:
  - 285°C for 30 min (IM7/PEKK)
  - 293°C for 30 min (IM7/PEEK)
  - No Cooldown Hold
- 26 Total Panels



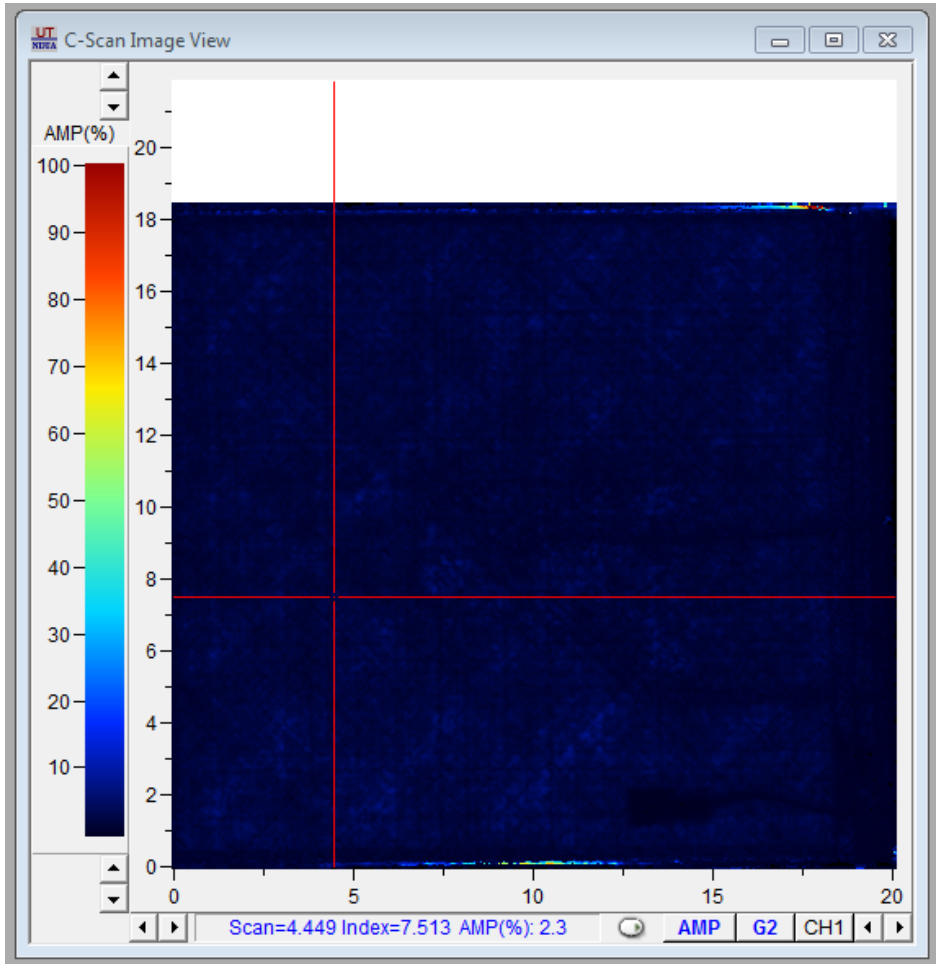
Ultrasonic Testing (UT) Comparison Charts

Solvay IM7/PEEK, 762 mm/s Layup Speed

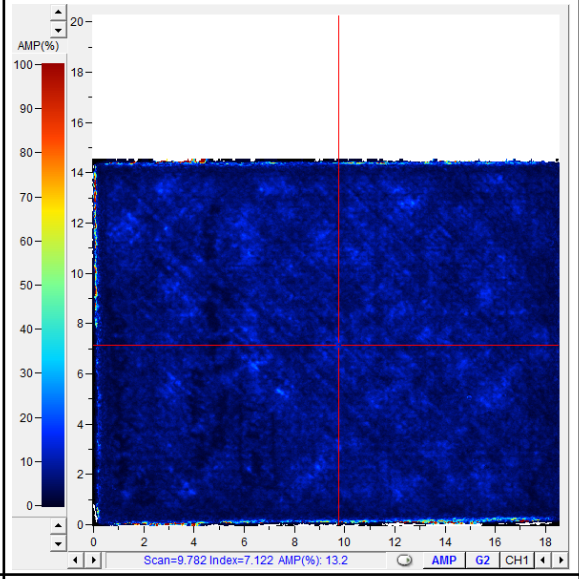
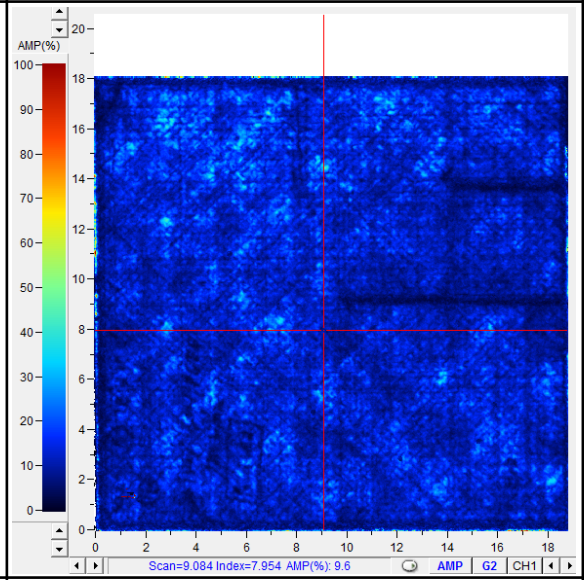
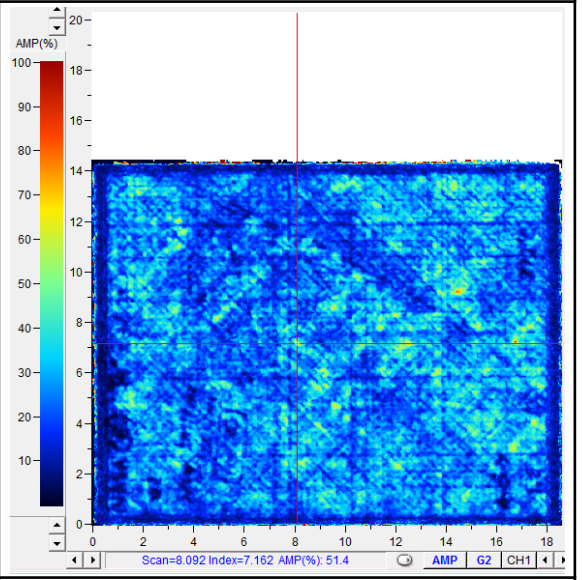
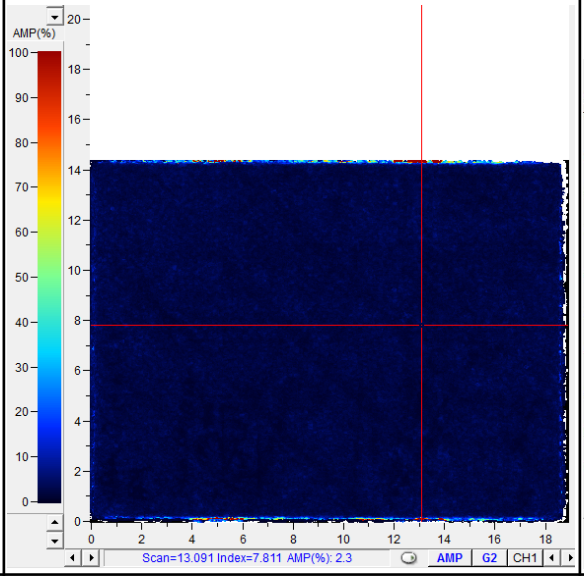
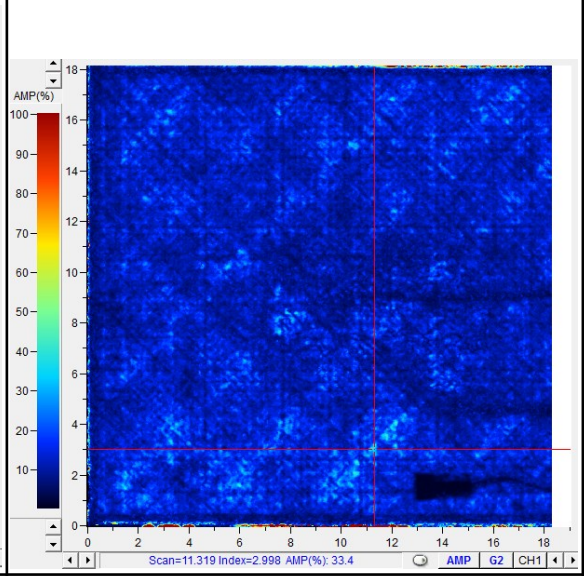
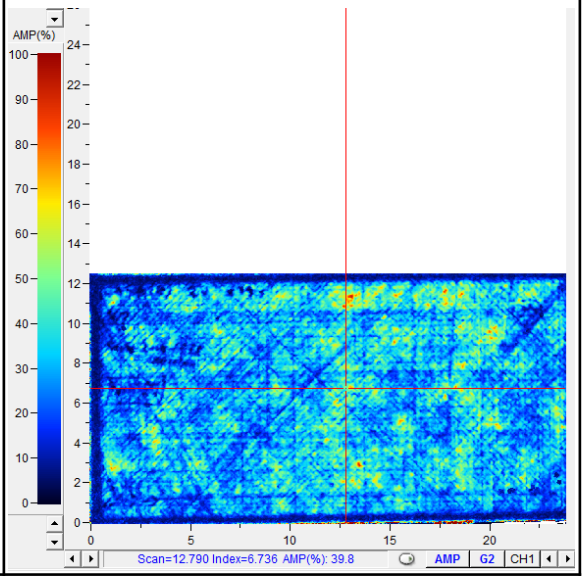
Autoclave (18.6 dB Gain)



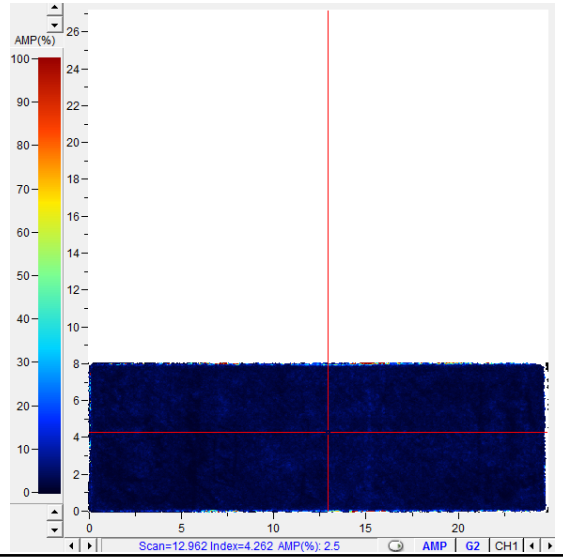
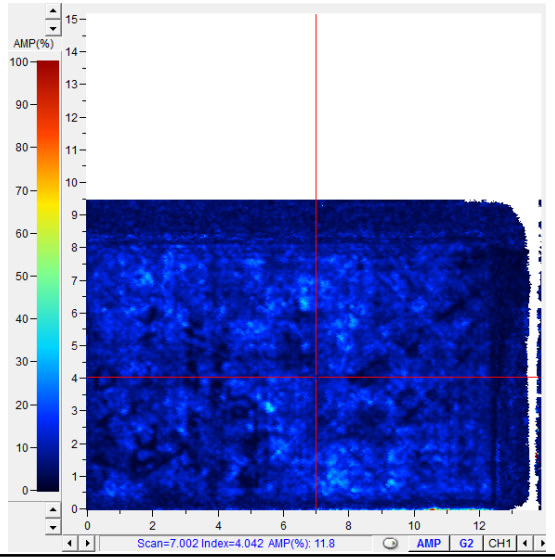
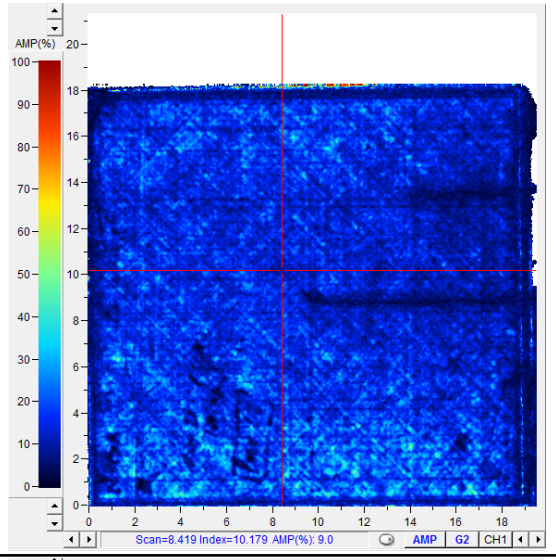
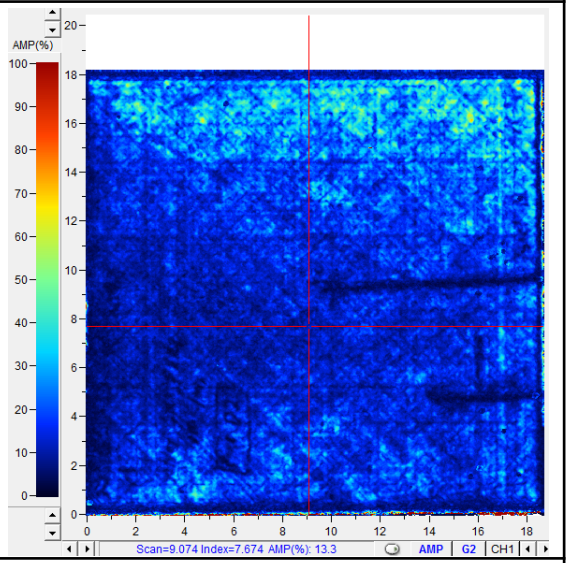
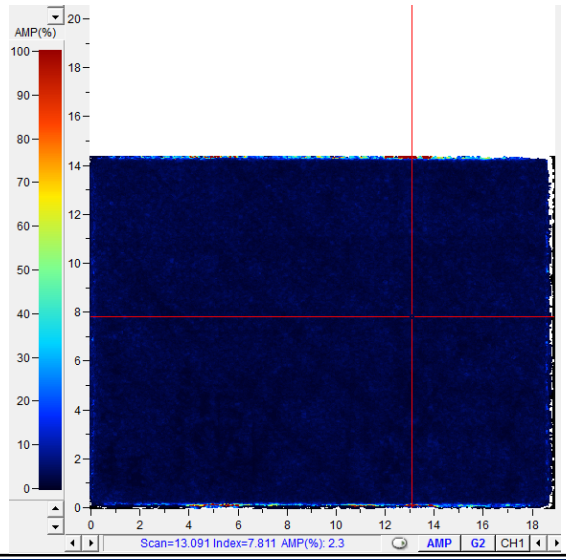
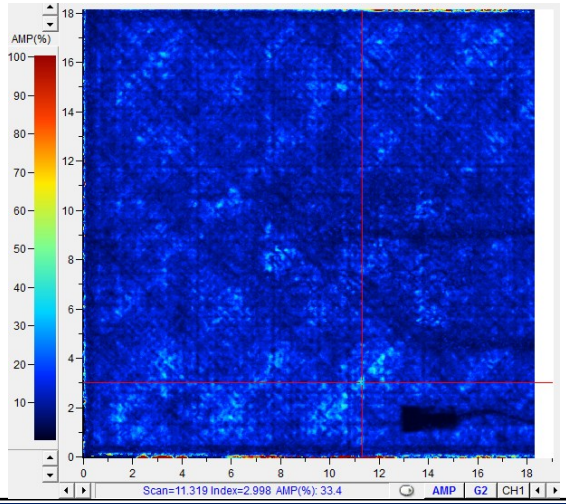
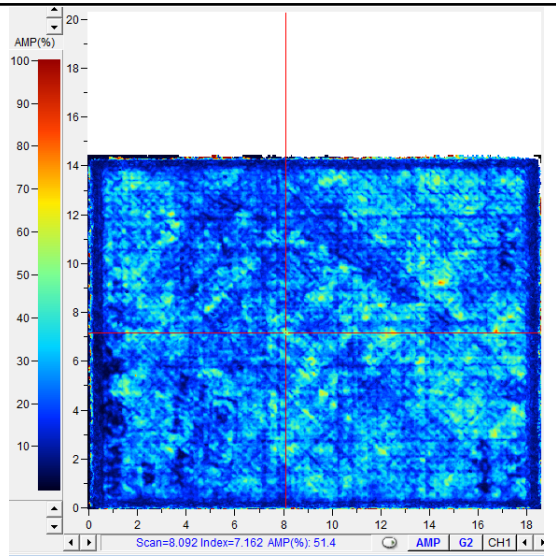
VBO – 60 min Consolidation Hold (18.6 dB Gain)



Solvay IM7/PEEK, VBO, 762 mm/s, 34.3 dB Gain

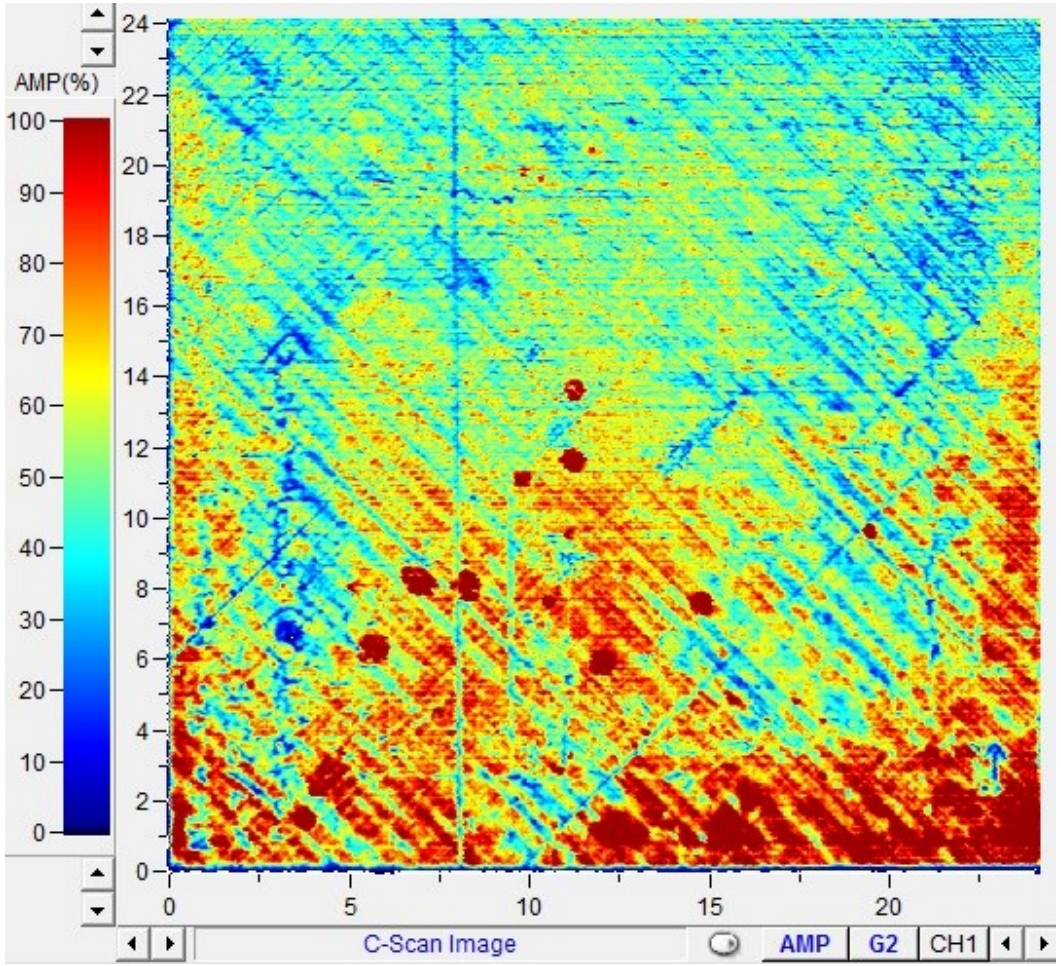
	5 min Consolidation Hold	60 min Consolidation Hold	120 min Consolidation Hold
Pre-consolidation Hold (320°C for 3 h)			
No Pre-consolidation Hold			

Solvay IM7/PEEK, VBO Panels, 34.3 dB Gain

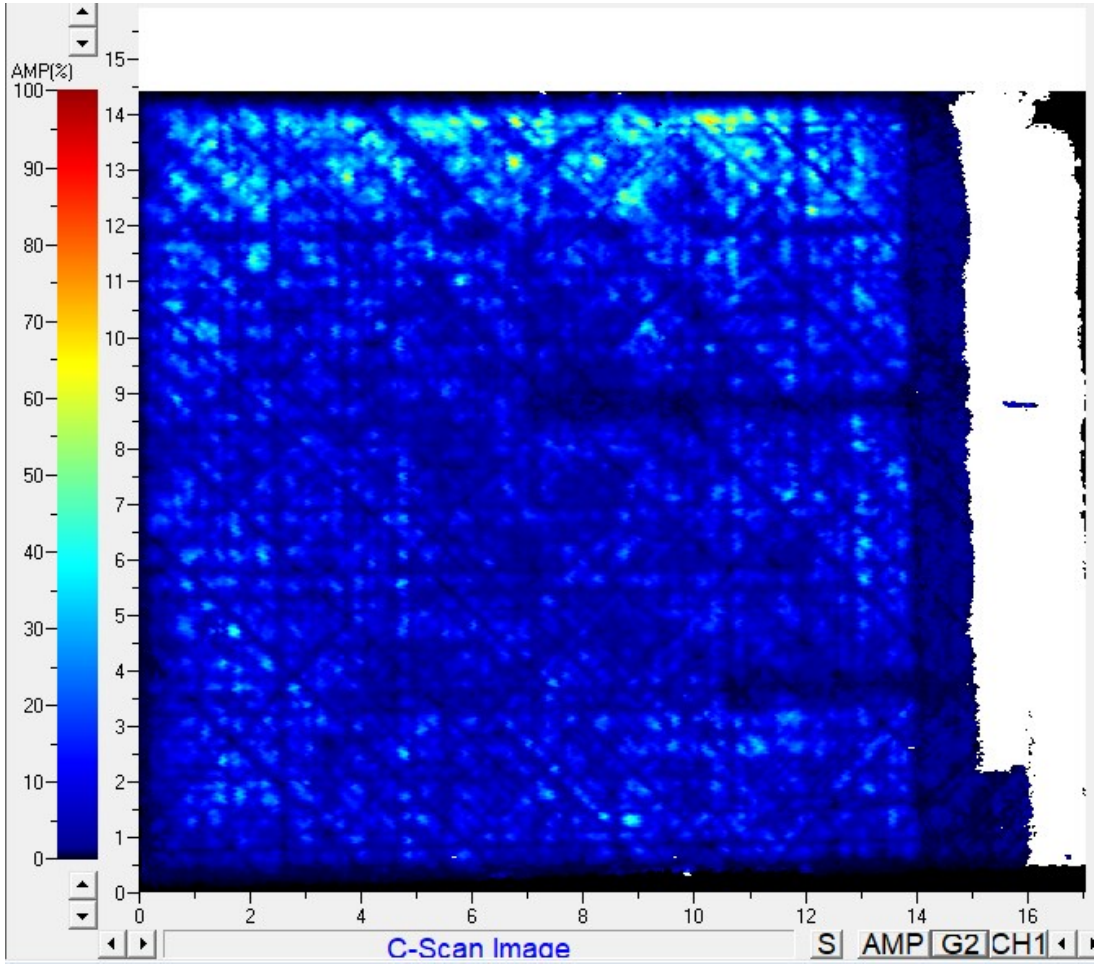
	5 min Consolidation Hold No Pre-consolidation Hold	60 min Consolidation Hold No Pre-consolidation Hold	120 min Consolidation Hold With Pre-consolidation Hold	180 min Consolidation Hold With Pre-consolidation Hold
423 mm/s Layup Speed				
762 mm/s Layup Speed				

IM7/PEKK, 762 mm/s Layup Speed

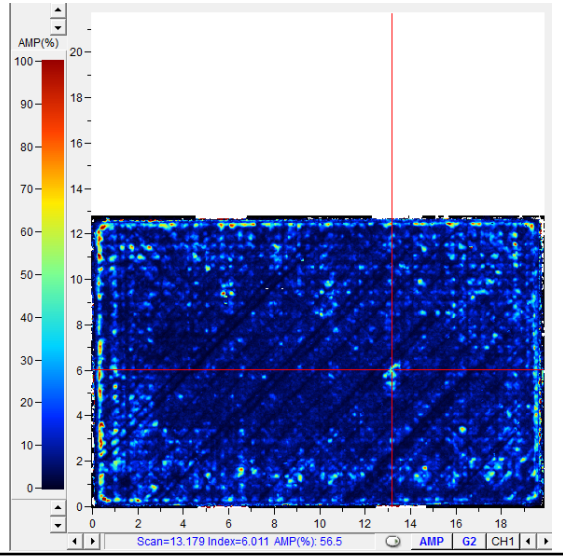
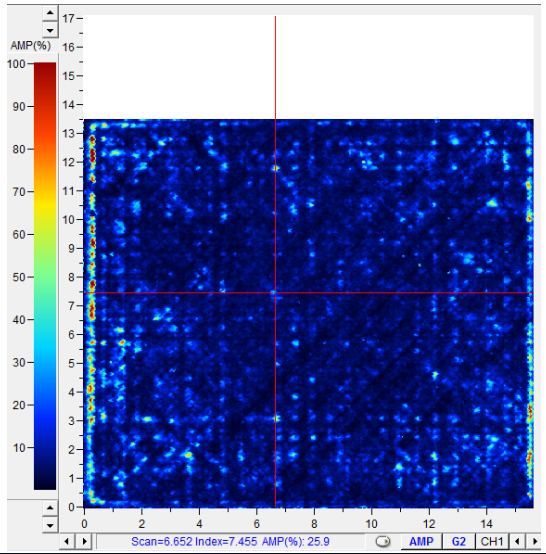
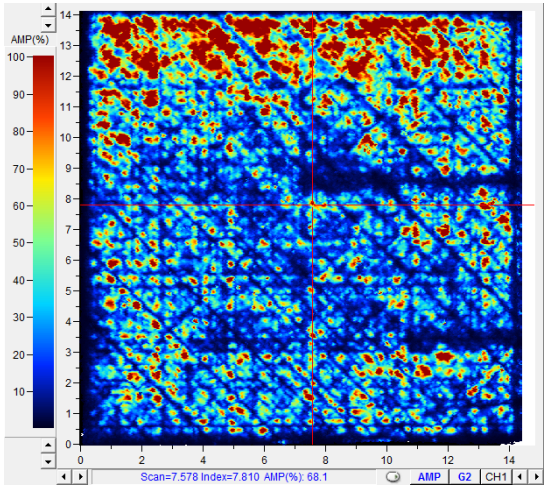
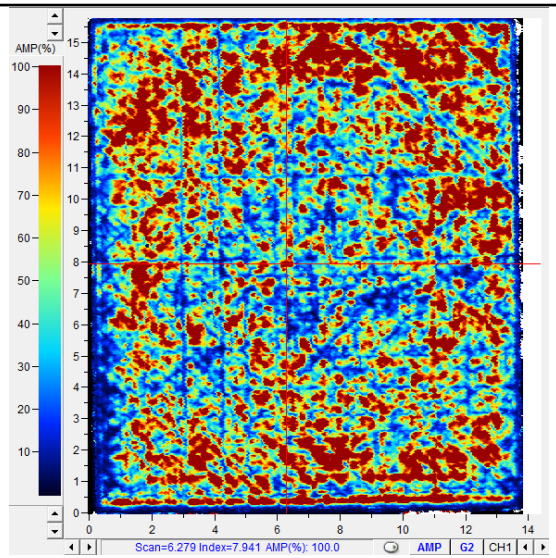
Autoclave (18.6 dB Gain)



VBO – 60 min Consolidation Hold (18.6 dB Gain)

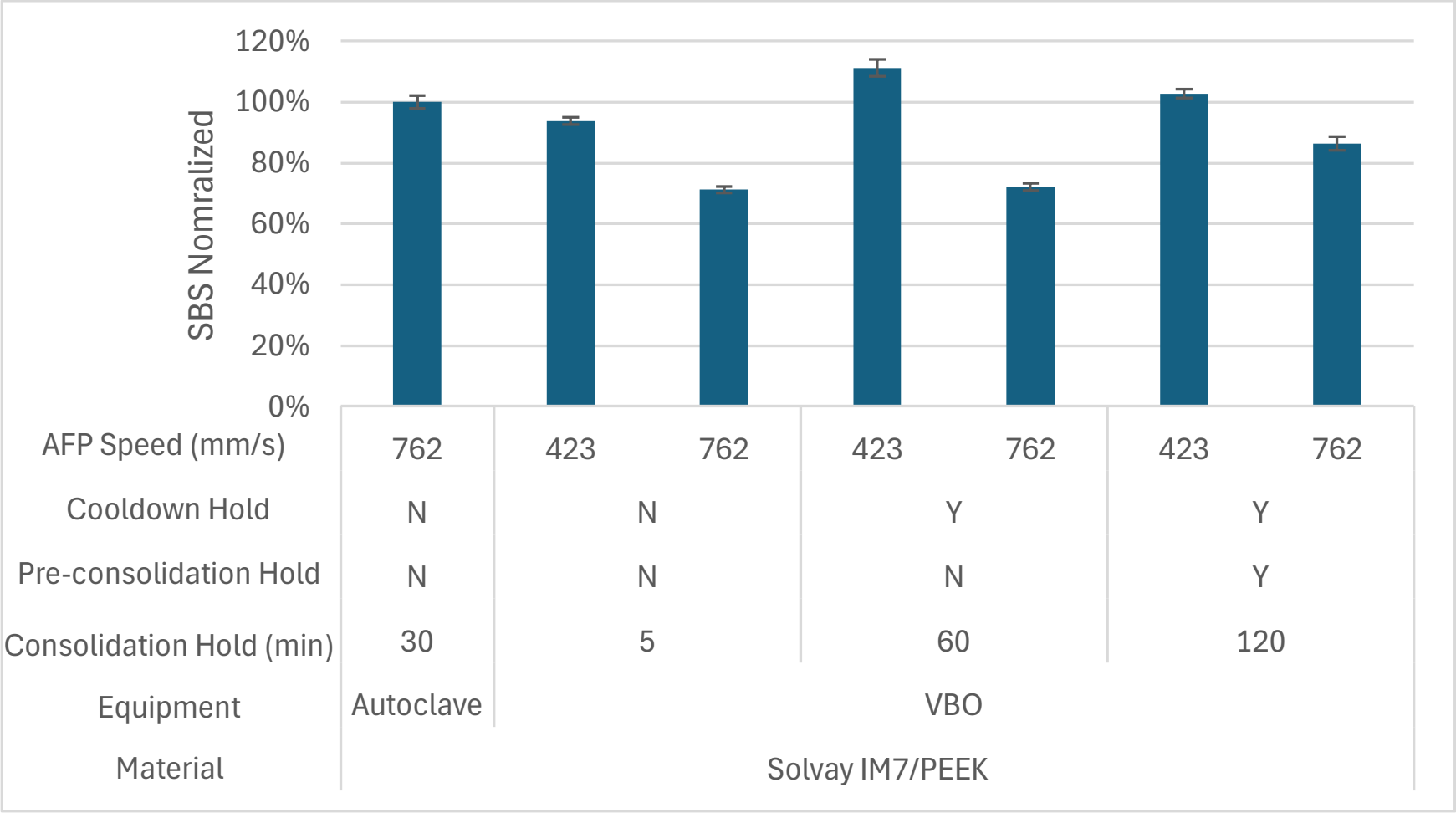


IM7/PEKK, VBO Panels, 34.3 dB Gain

	5 min Consolidation Hold No Pre-consolidation Hold	60 min Consolidation Hold No Pre-consolidation Hold	120 min Consolidation Hold With Pre-consolidation Hold
423 mm/s Layup Speed			
762 mm/s Layup Speed			

Mechanical Test Results: Short Beam Strength (SBS)

SBS Results: Layup Speed (IM7/PEEK)

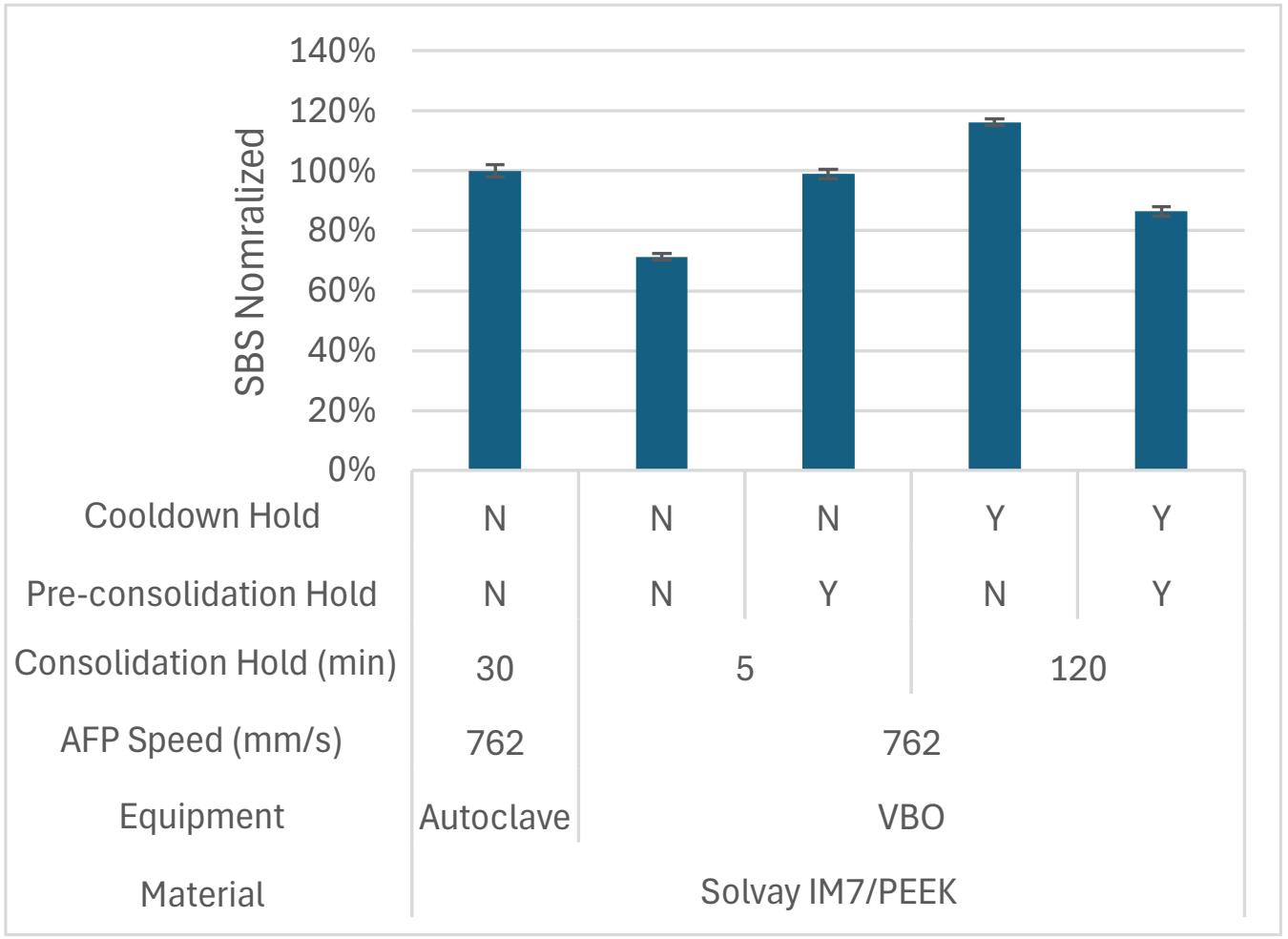


Result: IM7/PEEK panels with layup speed of 423 mm/s outperformed panels with layup speed of 762 mm/s

SBS Results: Consolidation Duration (IM7/PEEK)

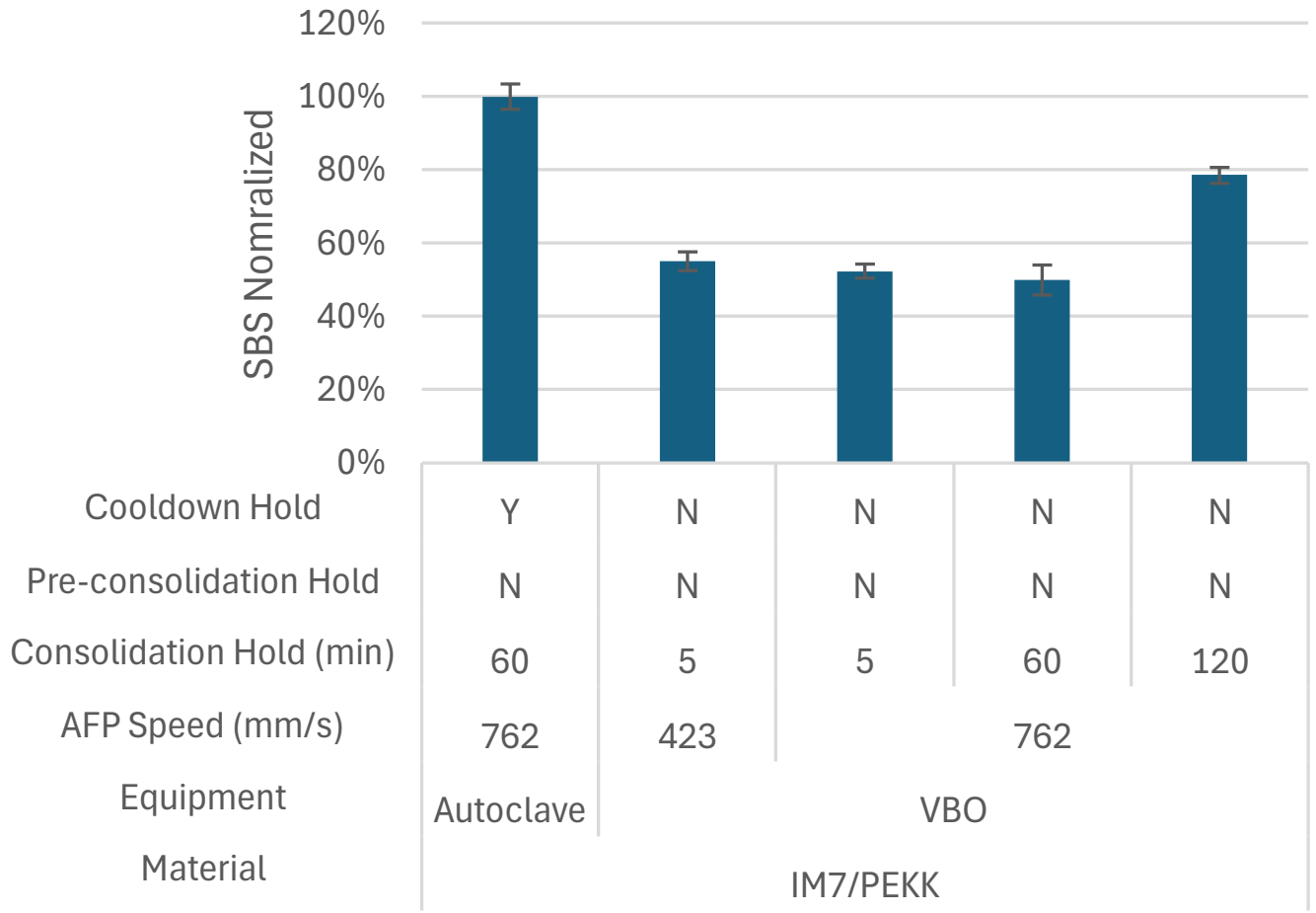
Result: Longer consolidation duration improved strength (overall tend)

SBS Results: Pre-consolidation Step (IM7/PEEK)



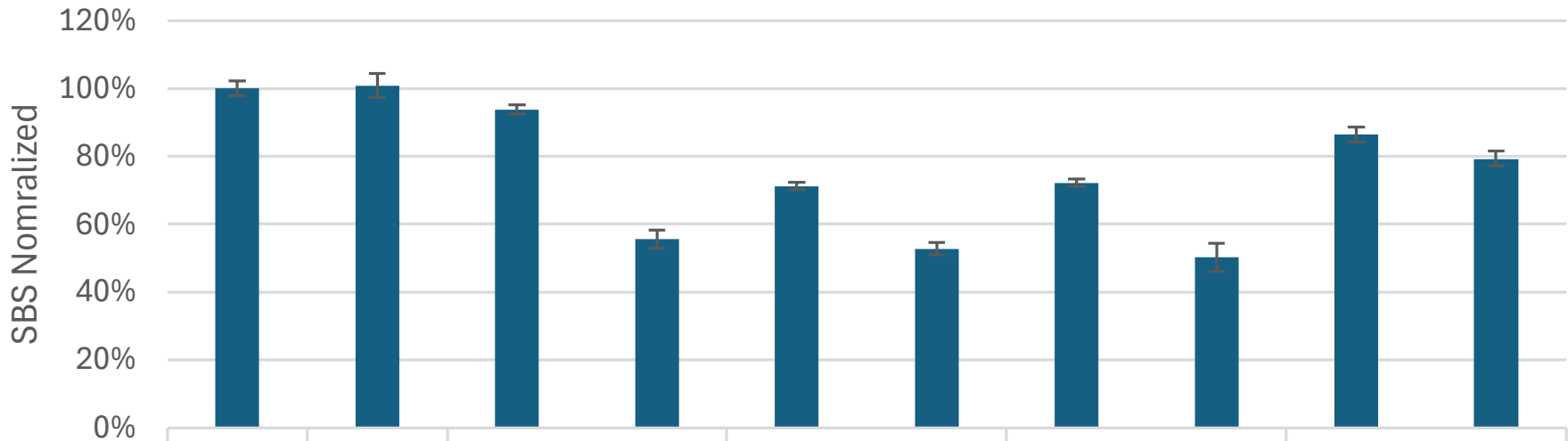
Result: Pre-consolidation step improved strength significantly on 5 min hold.
120 min hold panel with pre-consolidation and cooldown holds underperformed expectations.

SBS Results: IM7/PEKK



Result: VBO SBS for IM7/PEKK all below autoclave consolidation. Longer consolidation hold duration for VBO increases SBS.

SBS Results: Material comparison

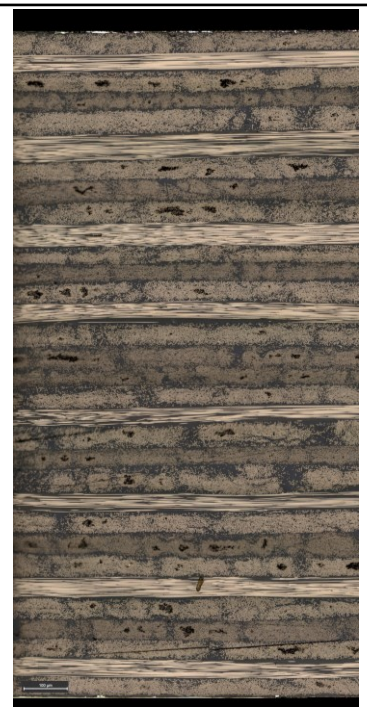
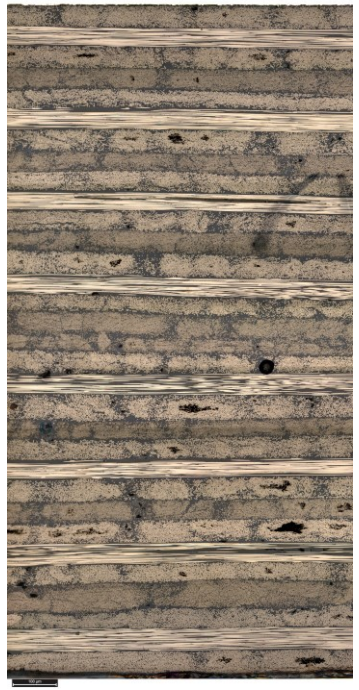


Material	IM7/PEEK	IM7/PEKK	IM7/PEEK	IM7/PEKK	IM7/PEEK	IM7/PEKK	IM7/PEEK	IM7/PEKK	IM7/PEEK	IM7/PEKK
Cooldown Hold	N	Y	N		N		Y		Y	
Pre-consolidation Hold	N	N	N		N		N		Y	
Consolidation Hold (min)	30	60	5		5		60		120	
AFP Speed (mm/s)	762		423		762					
Equipment	Autoclave		VBO							

Result: SBS from autoclave consolidation almost identical for both materials. IM7/PEEK outperformed IM7/PEKK for all VBO cases.

Photomicroscopy Analysis

IM7/PEEK Microscopy

Equipment	Autoclave	VBO	VBO	VBO
Consolidation Hold (min)	30	5	60	120
Preconsolidation Hold	N	N	N	N
Cooldown Hold	N	N	Y	Y
AFP Speed	762 mm/s	762 mm/s	762 mm/s	762 mm/s
				

IM7/PEKK Microscopy

Equipment	Autoclave	VBO	VBO	VBO
Consolidation Hold (min)	30	5	60	120
Preconsolidation Hold	N	N	N	N
Cooldown Hold	N	N	Y	Y
AFP Speed	762 mm/s	762 mm/s	762 mm/s	762 mm/s
				

Key Learnings and Conclusions

- Layup speed: IM7/PEEK panels at 423 mm/s outperformed 762 mm/s
  - Layup speed not necessarily the causal factor (i.e., correlation instead of causation) (e.g., higher laser power used for 762 mm/s layup speed to achieve similar levels of tact).
- Consolidation duration: Longer duration improved strength (Overall Trend)
  - One outlier: IM7/PEEK panel with 120 min consolidation hold, pre-consolidation hold, and cooldown hold underperformed expectations (did not align with trends).
- Pre-consolidation hold: Improved strength significantly on 5-minute consolidation hold
- Autoclave-level SBS achieved for Solvay IM7/PEEK with VBO consolidation
  - Autoclave-level SBS with VBO may be possible for IM7/PEKK with different cycle.

Questions?

Dr. Tyler B. Hudson
NASA Langley Research Center
757-864-3342
tyler.b.hudson@nasa.gov

STRUCTURES AND MATERIALS