Thermoplastic Composites Conference

Achieving the Renaissance in Manufacture of Large Integrated Aerostructures via Thermoplastic Composite Technologies

DeWayne Howell

Toray Advanced Composites

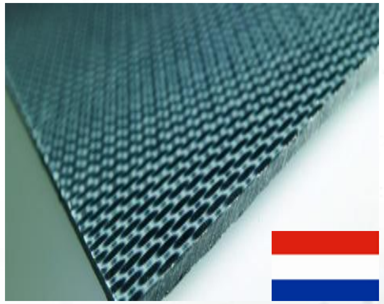
Material & Processes

Cetex® Thermoplastic Portfolio

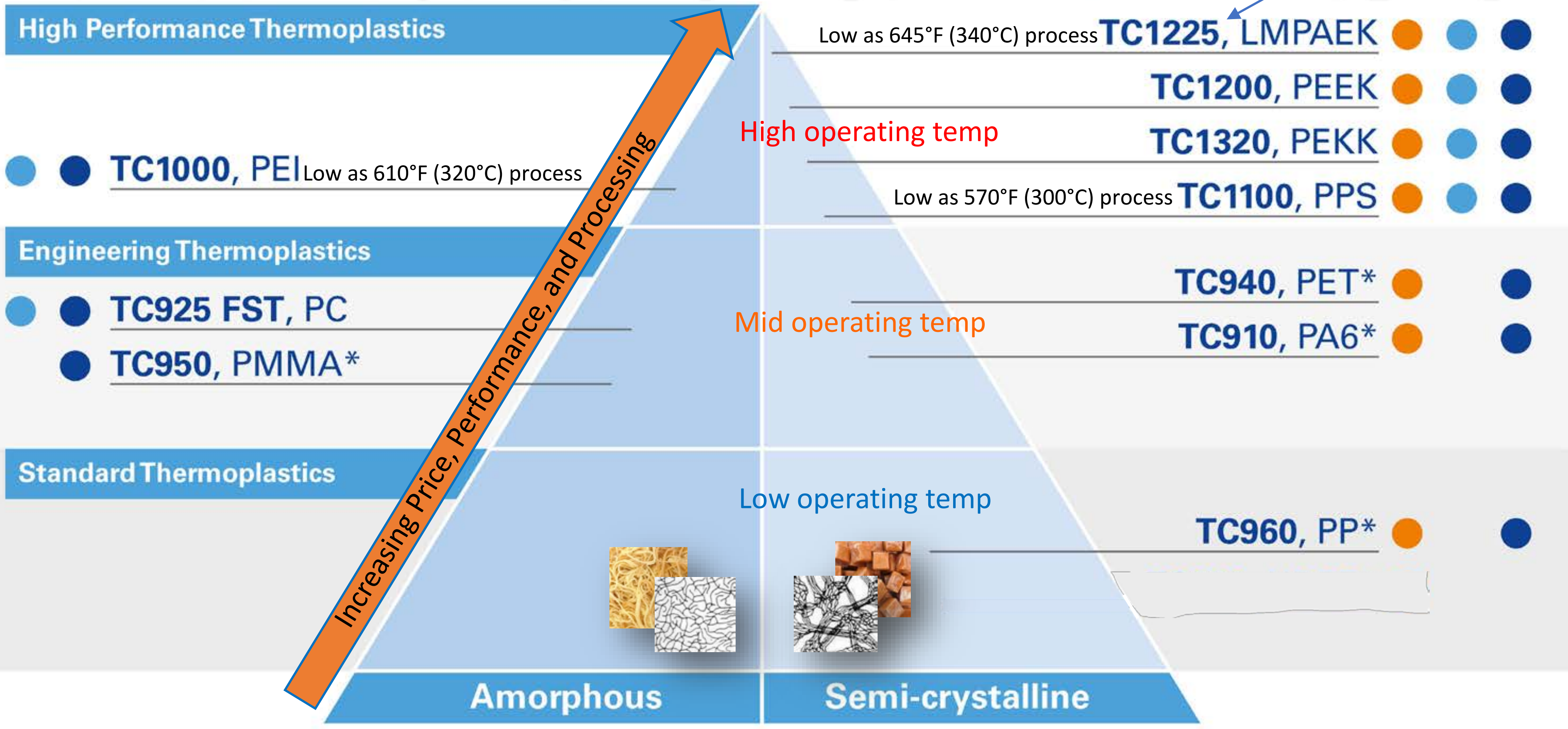
ANIFORM VIRTUAL FORMING

NCAMP Allowables Database

Unidirectional Tape
Bulk Molding Compound
Morgan Hill CA



Fabric Prepreg and Reinforced Laminates
Nijverdal, The Netherlands



● UD Tape ● Woven Prepreg ● Laminate * Laminate Parts

Major Benefits

- High H/W mechanicals
- Toughness
- FST
- Vibration dampening
- Chemical resistance
- Rapid processing
- Welding
- Overmolding

Part Fabrication Processes

Thermoplastic Focused Processes

HAND LAYUP:
- Slowest
- Versatile

AUTOCLAVE:
- Slow
- Expensive

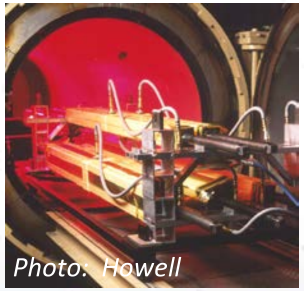


Photo: Howell

Automated Tape Layup (ATL):
- Fast (490 kg/h)
- High repeatability

Photo: Dieffnebacher

OVEN (OoA):
- Slow
- Less expensive

Photo: Wisconsin

Continuous Comp. Molding (CCM):
- Fast (~0.25 m/min per laminate)

Photo: ATC

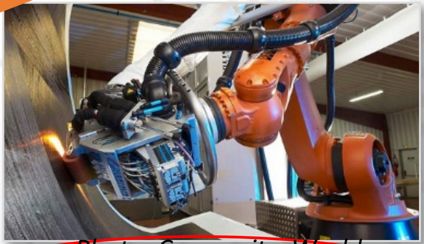


Photo: CompositesWorld

Auto. Fiber Placement (AFP):
- **Fast (1.7 m/s per course)**
- **+ OoA consolidation**
- In-situ speeds at 0.5 m/s

Stamp Forming:
- Fastest
- High repeatability

Photo: Howell

Photo: TPRC

Overmolding:
- Fast
- Complex stiffening

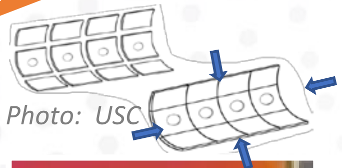
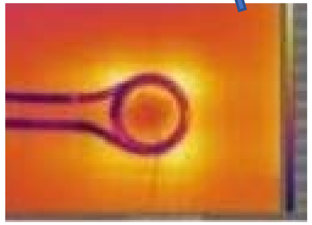


Photo: USC

Compression Molding
- Faster
- Complex parts



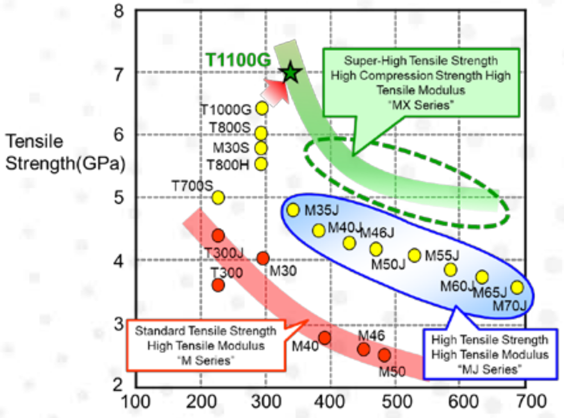
Assembly
- Welding

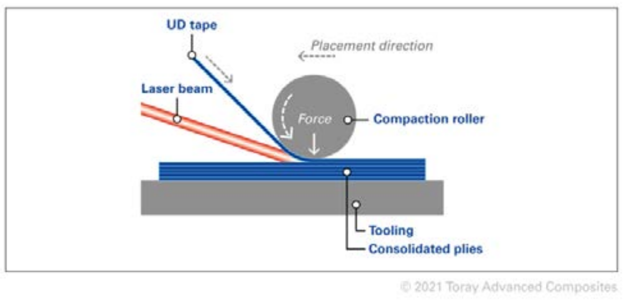
Protype — Ltd. Production — Mid Volume Production — High Volume Production

Automated Fiber Placement Trials

AFP Trial Goals

- Automated Fiber Placement (AFP) with LMPAEK
  - TC1225 LMPAEK T1100 145gsm 34%RC ¼” slit tape
  - For comparison both TC1200 PEEK T1100 and TC1320 PEKK AS4 were also tested
- AFP + OoA consolidation focus
  - offers higher throughput than In-situ
- High speed layup for rapid processing facilitates ease of tow replacement
- Working with Electroimpact and Janicki






Photos: Electroimpact

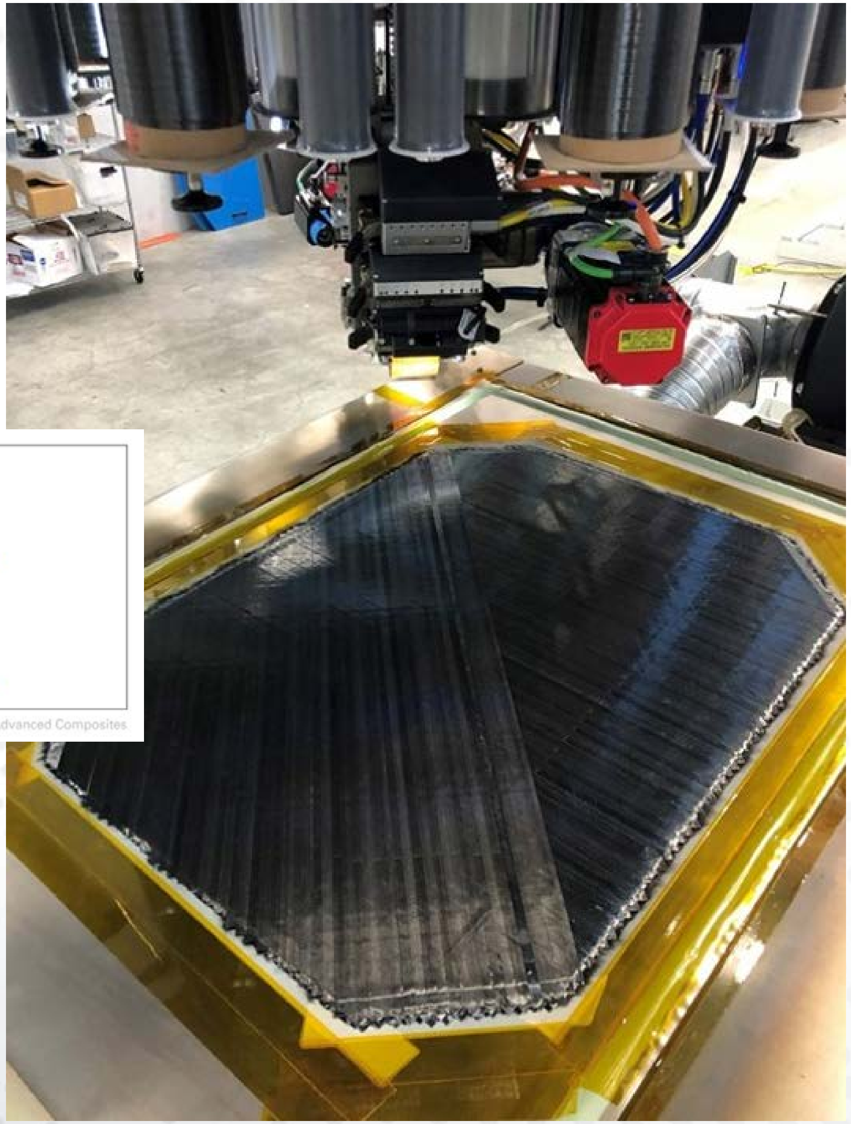


Photo: Electroimpact

AFP Process

Video: Electroimpact

- Electroimpact system uses laser heating, directed beam per tow (Variable-Spot-Size Laser) to optimize heating across individual tows in a course
- Tack level can be adjusted by laser power and speed
- EI has demonstrated course layup speeds of 4000 in/min (~100 m/min) – 4-to-6 times increase in productivity

AFP Setup

- 18”x24” panel size
- 8 tows/course
- 1,600 in/min speed
  - Panel size too small for 4,000 ipm
- 350°C targeted at nip point
  - Below normal 365C processing temp for low tack

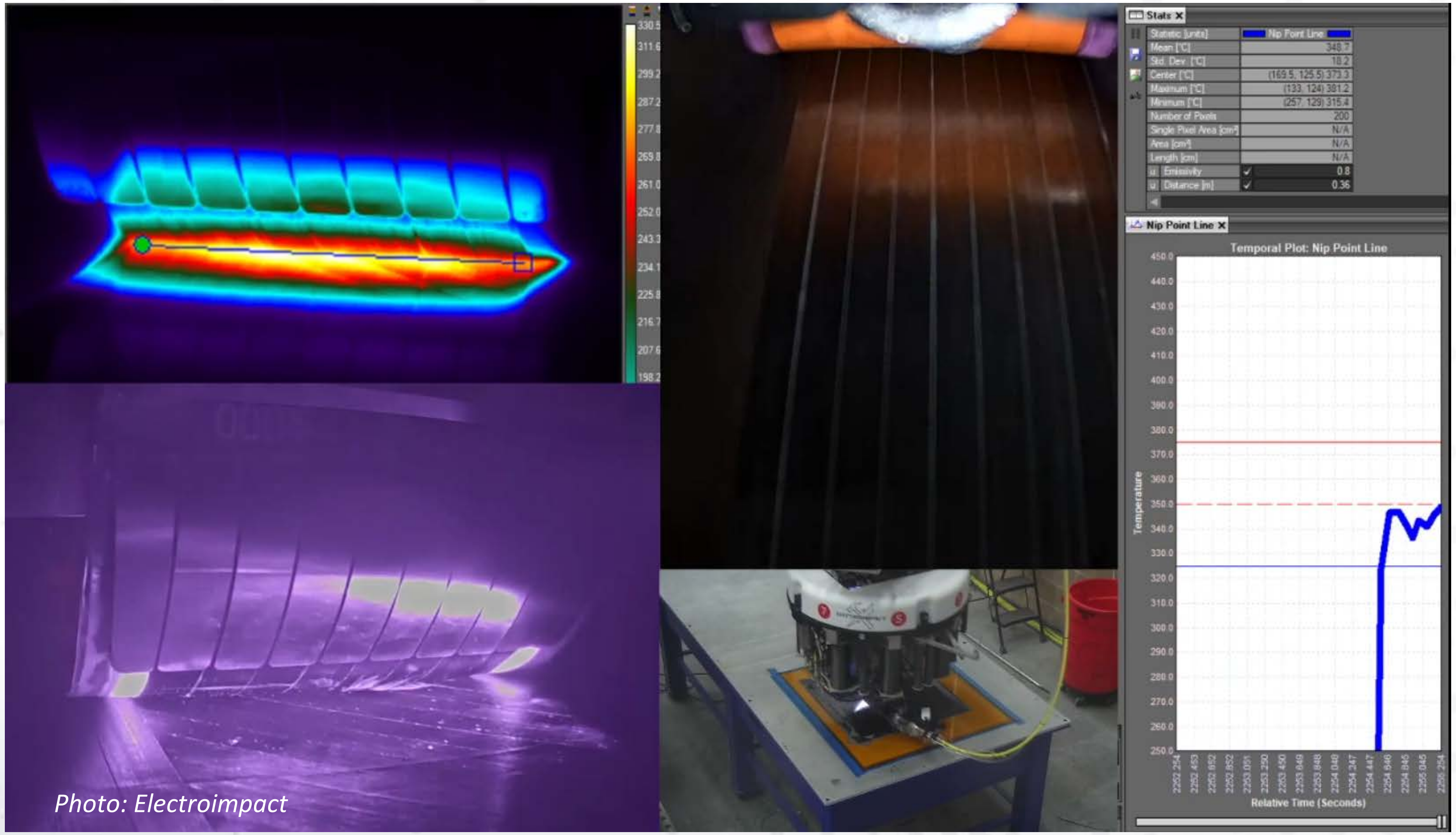


Photo: Electroimpact

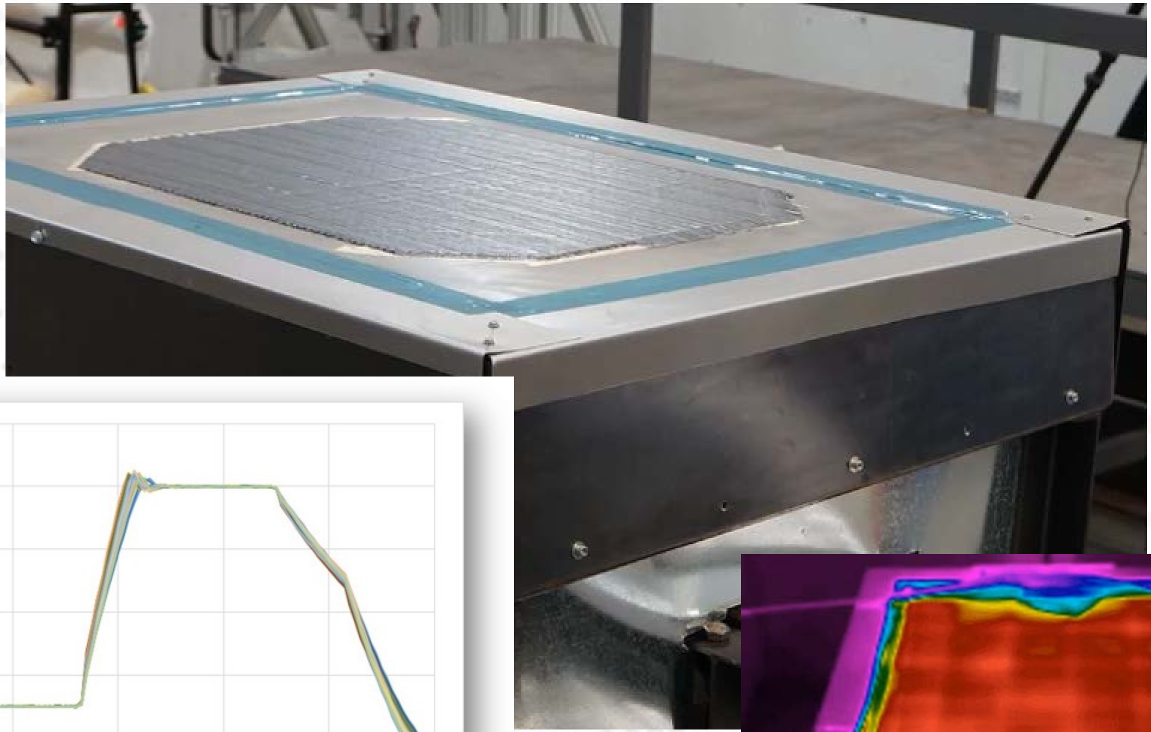
AFP Tow Replacement

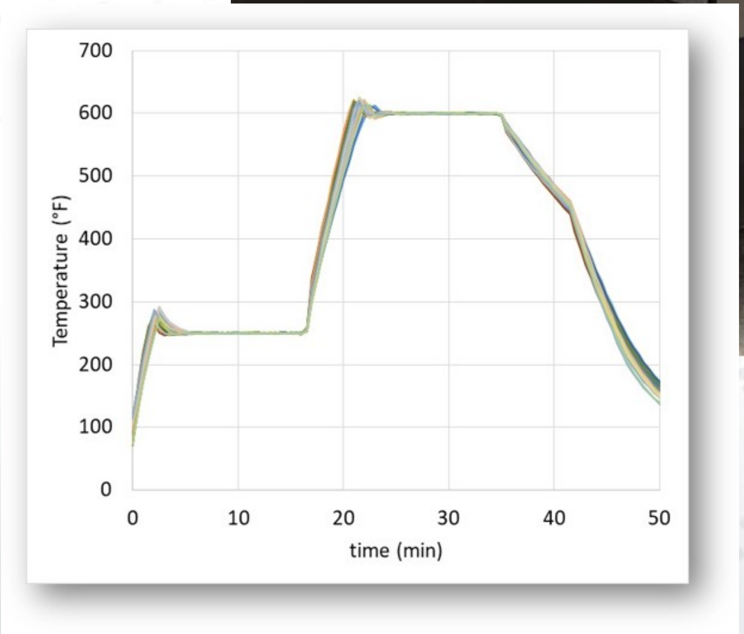
Photo: Electroimpact

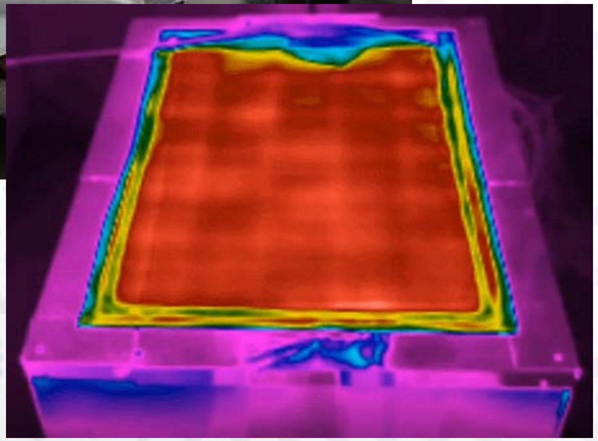
- Balance between tack level and nip temperature – 350°C gave moderate tack for TC1225 LMPAEK T1100
- Remove tow without displacing tows beneath
- Removed and replaced tows several times within a layup
- Resulted in laminate that is semi-consolidated through the thickness

VBO Consolidation Process

- The Janicki VBO process utilizes highly distributed tool side uniform heating and cooling for very fast consolidation process cycles and can be scaled for large area parts.

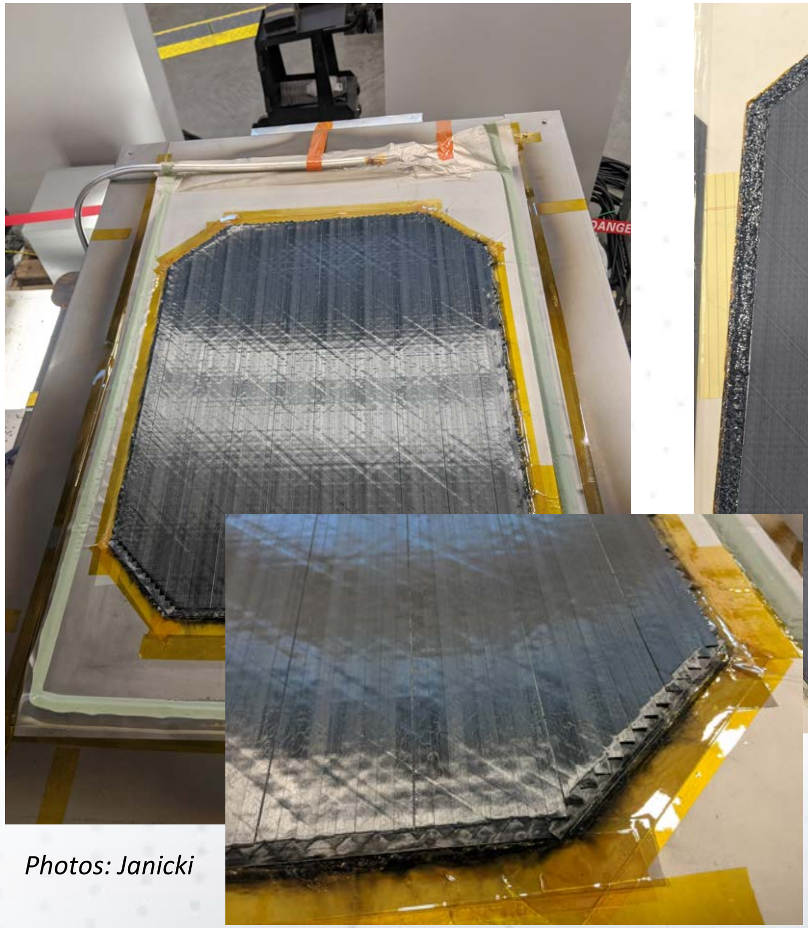


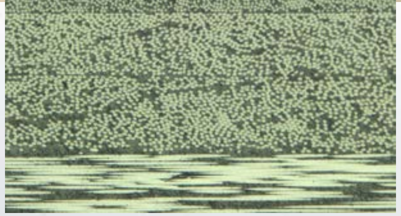




Photos: Janicki

JANICKI INDUSTRIES Demonstrates Low Void Consolidation

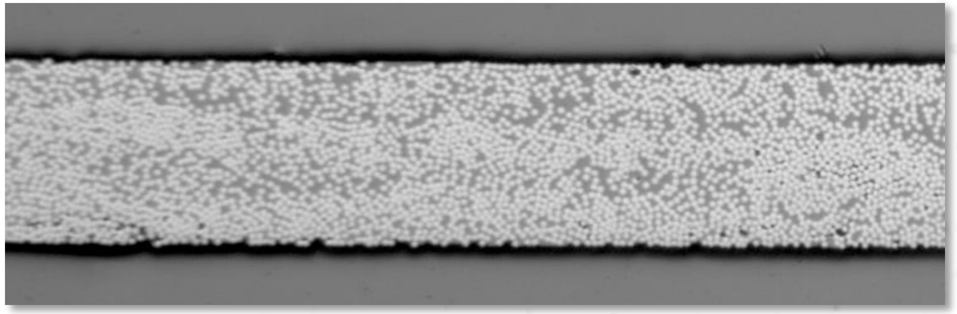




Photos: Janicki

- TC1225 LMPAEK T700
- Vacuum bag only pressure
- Near ZERO voids
- Achieved by controlling the key stages of melt, flow, and crystallization with precise temperature control.
- Findings from previous work done by EI and Janicki

TC1225 LMPAEK Enabler for AFP + VBO



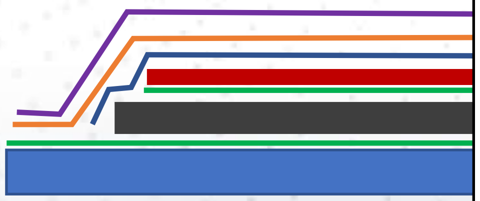
Typical cross-section of TC1225 UD tape

Physical data	
Glass Transition Temperature (°C)	147
Melt Temperature (°C)	305
Crystallization Enthalpy (J/g)	130

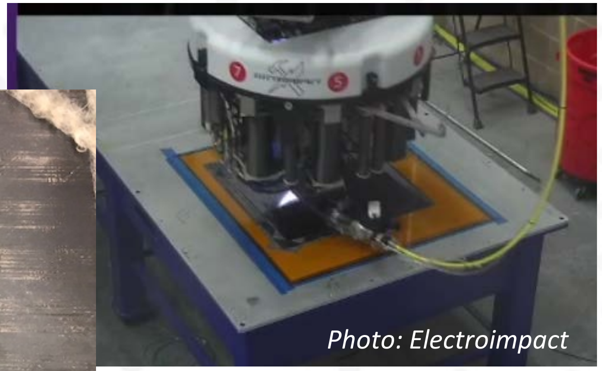
- The lower viscosity of TC1225 LMPAEK compared to TC1320 PEKK or TC1200 PEEK
- Should give an advantage in the elimination of voids during AFP+ VBO.
  - There are three void evacuation mechanisms: diffusion through the thickness, in-plane air evacuation and void filling.
  - Lower viscosity will allow for easier flow into void areas of a laminate that can occur at ply drops or at tow gaps.
- AFP laydown speed: Lower viscosity polymer can flow into void areas more quickly before the compaction head passes over a feature and the TC1225 LMPAEK solidifies, thereby allowing for higher speeds to fill a given void.
- Uniform fiber distribution and constant thickness crossection UD slit tape results in improved AFP layup quality (especially for in-situ)

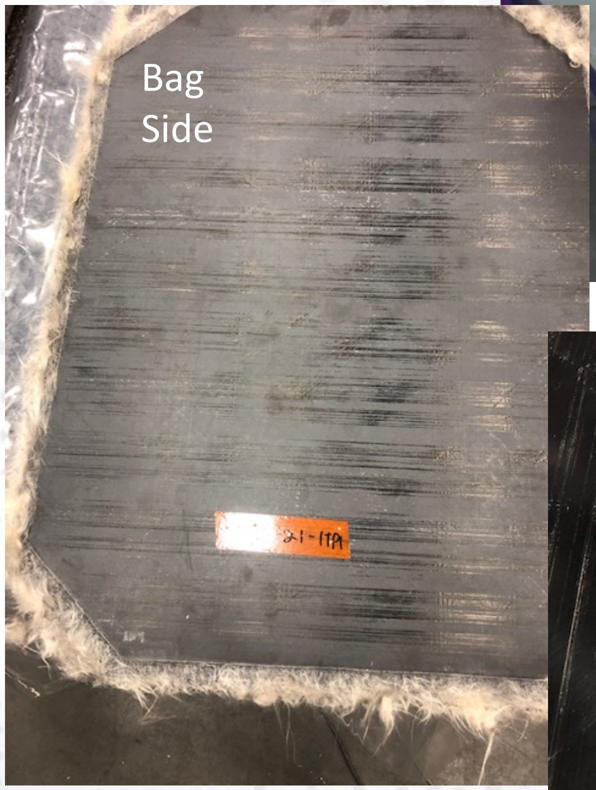
Trial Results for TC1225 LMPAEK T1100

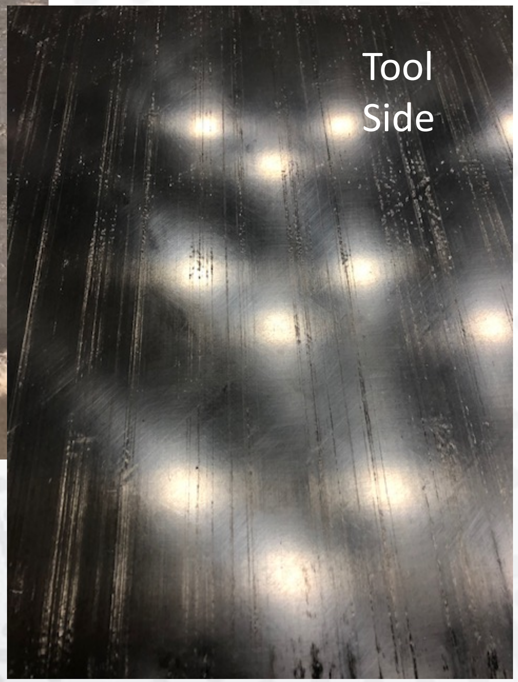
- AFP laydown was very good
- Janicki VBO tool consolidation cycle
  - 100F/min to 250F, hold 5m, 100F/min to 365C, hold 30m, 100F to 290C, hold 5m, 100F to cool



Insulation
Vacuum Bag
Non-woven Fg Breather
Steel Caul Sheet
Release Agent
Laminate
Release Agent
Tool Plate

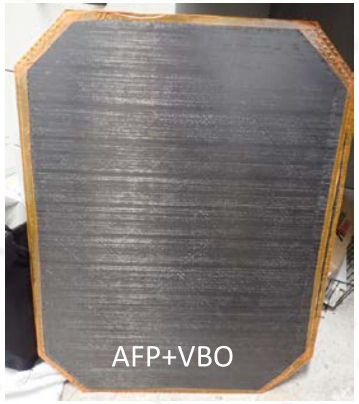


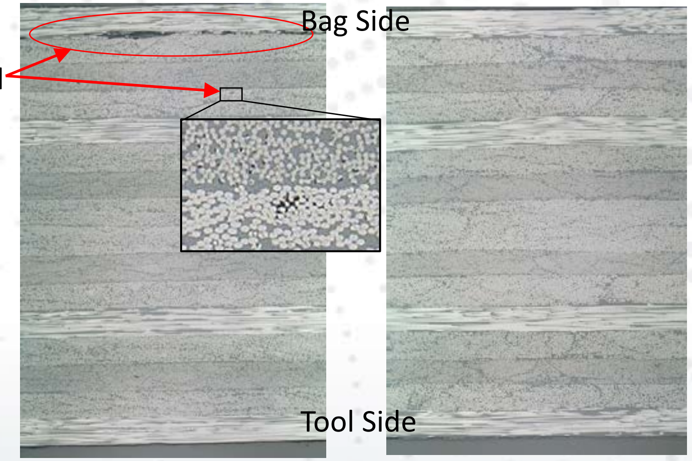


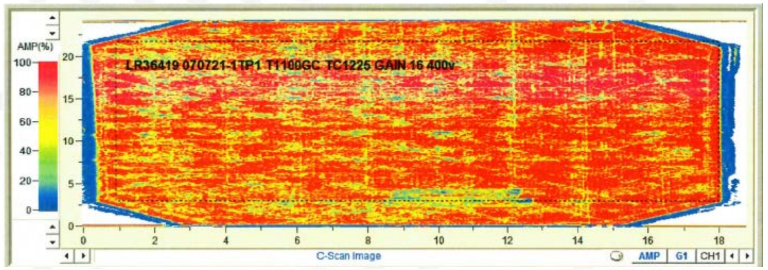


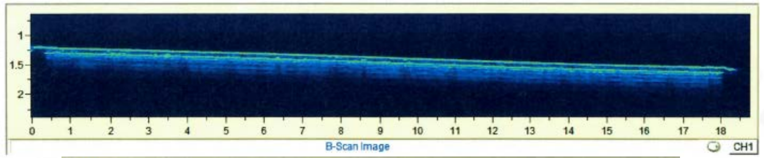
Trial Results for TC1225 LMPAEK T1100

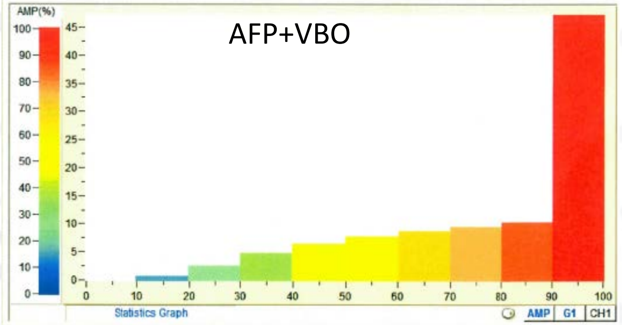
- Process was not optimized.
- C-Scan shows surface roughness.
- Tow gaps, on order of 0.01”, and 16 ply vs 24 ply testing may contribute to strength differences compared to press.
- Longer dwell, and slightly higher consolidation temperature, along with higher nip point temperature during AFP would help to increase strength. Optimization trials would be the next step.
- Acid digest gives low void content & micrograph confirms. Dominant void between last and 2nd to last ply will affect strength.
- OHC is very good.
- AFP+VBO+Press increases strength over AFP+VBO by ~8%











Panel	Layup	Thick (in)	PPT (in)	UNC (ksi)	UNCm (Msi)	OHC (ksi)	OHCm (Msi)	UNT (ksi)	UNTm (ksi)	SBS (ksi)	Fv	Rc (wt)	Voids
AFP + VBO (1 panel)	16 ply QI	0.0906	0.0057	65.2 (0.9)	8.2 (0.18)	43.4 (0.85)	6.2 (0.57)	133.3 (1.7)	8.6 (0.02)	11.9 (1.0)	57.50%	34.40%	1.10%
Layup + Press (>1 panels)	24 ply QI	0.144	0.006	85.0	8.5	45.0	--	180.0	8.5	13.0	--	34.00%	0.40%
% of L+Press	--	--	--	77%	96%	96%	--	74%	101%	92%	--	--	275%
Average values with (STDEV)													

Large R&D Projects Leading Future Developments

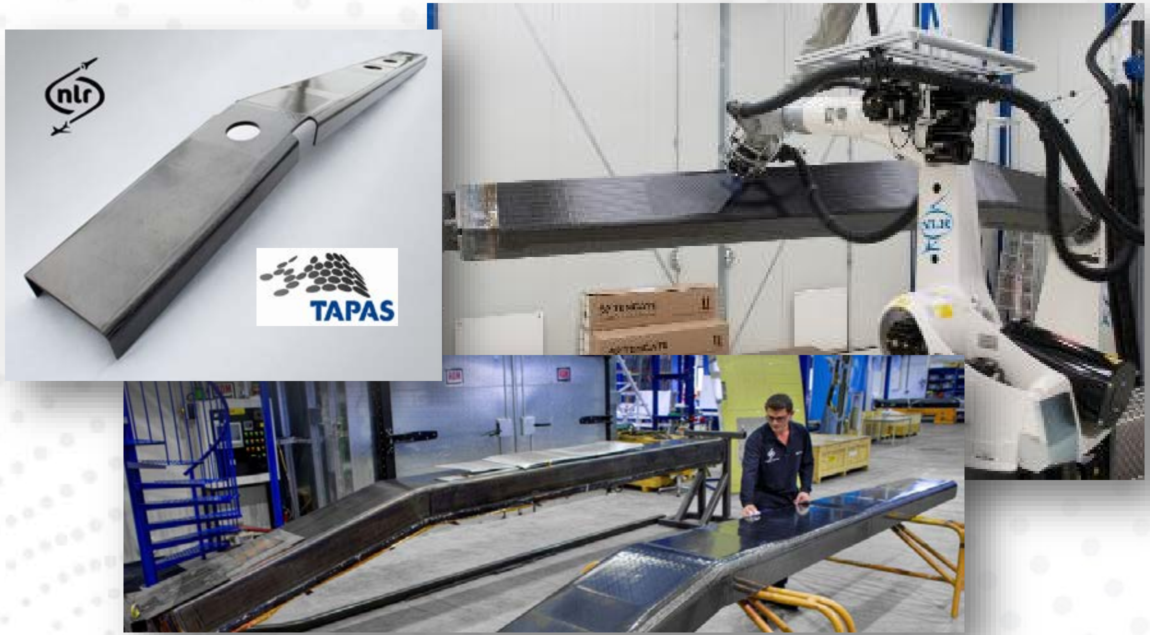
Rudder and Engine Pylon

Gulfstream G650 Rudder

- Cetex® TC1100 PPS CF
- Stamp form + induction weld
- Overnight automated induction welding
- 10% lighter and 20% lower cost than sandwich thermoset construction

Source: Gulfstream & Fokker

Source: NLR



Engine Pylon Top Spar Demonstrator

- Cetex® TC1320 PEKK AS4D
- Designed and Manufactured by NLR
- AFP + autoclave – Laser, Coriolis
- Part length approx. 6m
- Part thickness up to 28mm (1.1”)

Bulkhead ad Ruddervator

Source: DLR & Premium AEROTEC

Bell V-280 Valor Ruddervator Demonstrator

- Cetex® TC1100 PPS CF
- GKN Aerospace fabricated
- Induction welded
- Advanced thermoplastic Ruddervators significantly reduce weight, cost and part count. + access door from scrap
- Still flying on the demonstrator today

Source: Bell & CompositesWorld

Pressure Bulkhead Demonstrator

- Cetex® TC1100 PPS CF
- Airbus A320 rear bulkhead
- 8 stamp formed triangular sections resistance welded together
- 15% lighter, 10% lower cost, and reduction in process time by 75%

Clean Sky 2 Multifunctional Fuselage Demonstrator

- Cetex® TC1225 LMPAEK CF
- Automated fiber placement (AFP)
- Fuselage skins fabricated in two 90-degree segments and joined via co-consolidation
- Resistance, Ultrasonic and Conduction Welding
- TPC fuselage skins, frames, stringers , beams and door frames
- Multi company participation
- 10 year program 2014-2024


Photo: NLR

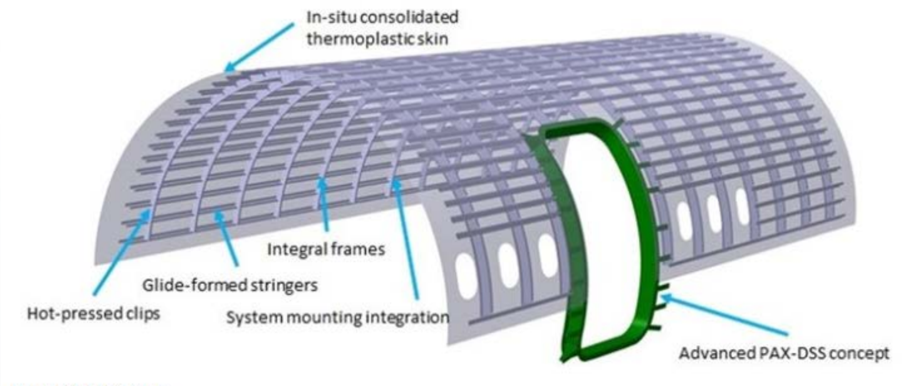
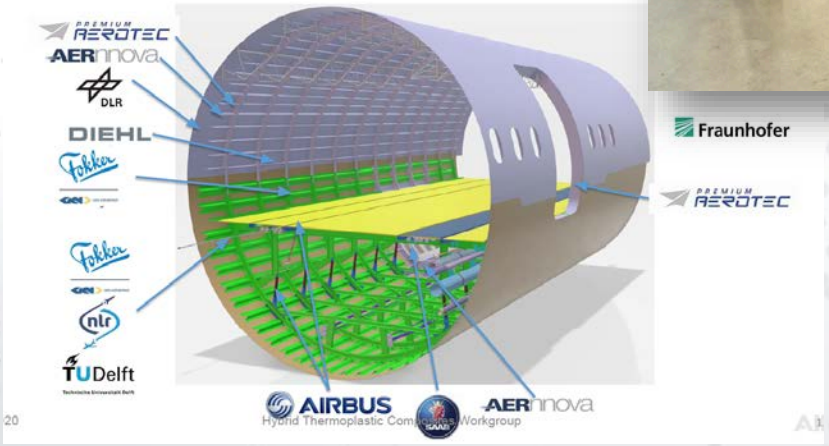
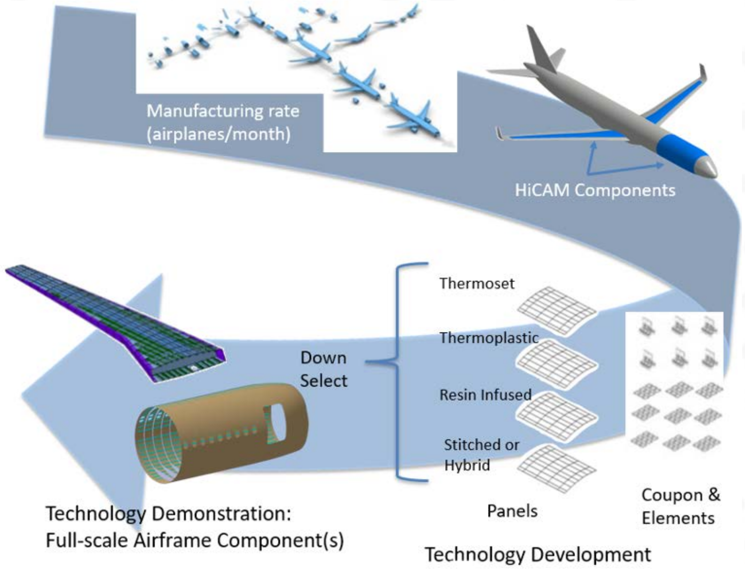


Photo Credit: DLR

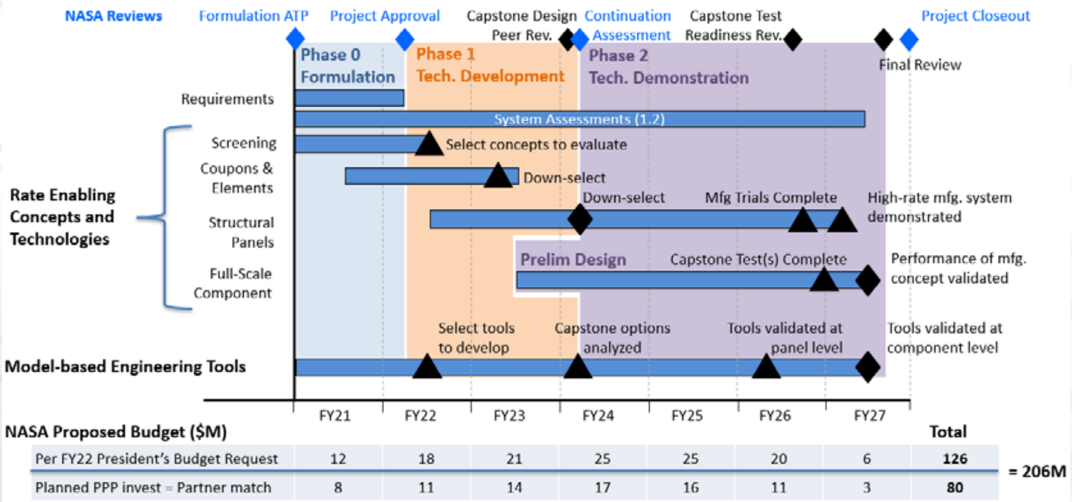


Hi-Rate Composite Aircraft Manufacturing (HiCAM)

- NASA partnering with industry to increase single isle **composite** aircraft manufacturing rate, reduce costs, and improve performance.
- **Performance Metrics:** 60 to 80 shipsets/mth, cost reduction 30% to 50% of baseline, <2% heavier than baseline, TRL 6 and MRL 6 by closeout.
- Develop model-based engineering tools for high-rate concepts.



Primary stakeholders	Current Partners
U.S. transport aircraft OEMs, and Tier 1 suppliers	Boeing, Spirit Aerosystems, Northrop Grumman, ATC
Other composites aerostructures for defense and engine applications	Collins Aerospace, GE Aviation, Lockheed Martin, Aurora Flight Sciences
Composite material suppliers	Hexcel, Toray, Solvay
Manufacturing and inspection equipment	Electroimpact
Engineering software developers	Collier Research Corp, CGTech, Convergent MT-U.S.
Universities – aero R&D, future workforce	Wichita State Univ., Univ. of South Carolina
FAA, preview emerging technology	FAA / Aviation Safety (AVS), WJH Technical Center



Source: NASA

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