

Epoxy and Polyimide Fiber Metal Laminates Made By The VARTM Process

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Problem Definition

The current manufacturing process for fiber metal laminates (FML) requires prepreg and an autoclave or press, the part size is limited by the size of the autoclave or press, and the process is expensive.



Objective

Reduce the cost of fiber metal laminates by manufacturing by the VARTM process with an ultimate goal of producing FML with the level of quality comparable to those of FML fabricated by autoclave.



Outline

- **Fiber Metal Laminates (FML, GLARE)**
- **Composites Processing by Resin Infusion (VARTM)**
- **VARTM of FML**
- **Fatigue Data of Foils and Laminates**
- **HT-VARTM of FML**
- **FML from Plasma Metal Deposition Process**
- **Summary**



GLARE Composition

GLARE (GLAss REinforced FML) is a type of hybrid laminate composed of thin layers of aluminum alloy alternating with glass fiber reinforced epoxy.

Commercially Available GLARE Grades

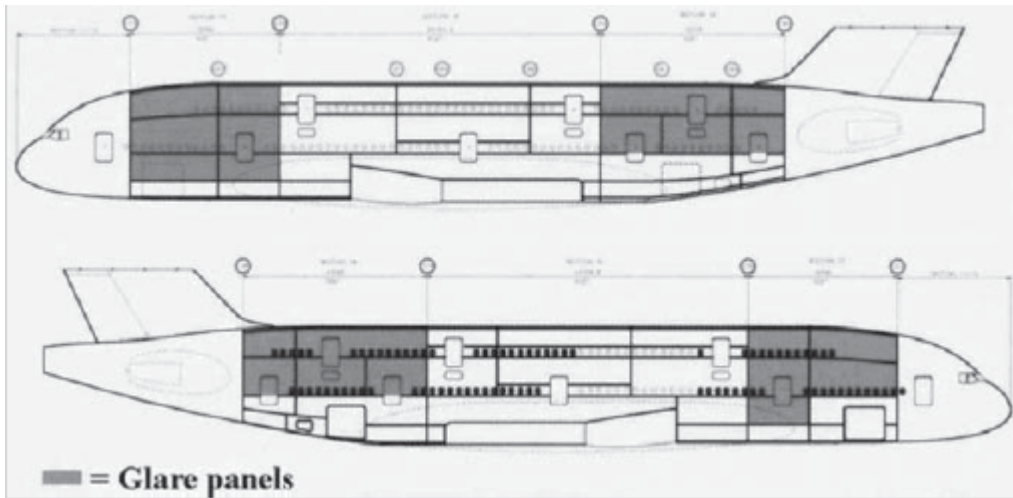
Grade	Al Layers		Fiber Layers		Typical Density (g/cm ³)
	Alloy	Thickness per Layer(mm)	Orientation	Thickness per Layer(mm)	
GLARE 1	7475-T76	0.3–0.4	Unidirectional	0.25	2.52
GLARE 2	2024-T3	0.2–0.5	Unidirectional	0.25	2.52
GLARE 3	2024-T3	0.2–0.5	0°/90° Cross-ply(50%-50%)	0.25	2.52
GLARE 4	2024-T3	0.2–0.5	0°/90°/0° Cross-ply(67%-33%)	0.375	2.45
GLARE 5	2024-T3	0.2–0.5	0°/90°/90°/0° Cross-ply(50%-50%)	0.5	2.38
GLARE 6	2024-T3	0.2–0.5	+45°/-45° Cross-ply(50%-50%)	0.25	2.52

Note: The typical density here refers to laminates with 0.3 mm aluminum thickness and 2/1 lay-up.

[1] Wu, Guocai, Yang, J.-M. The Mechanical Behavior of GLARE Laminates for Aircraft Structures

Applications

- **Airbus A380**
 - Fuselage material
 - Floors/ liners
- **Impact/ blast resistance cargo containers**



Airbus A380

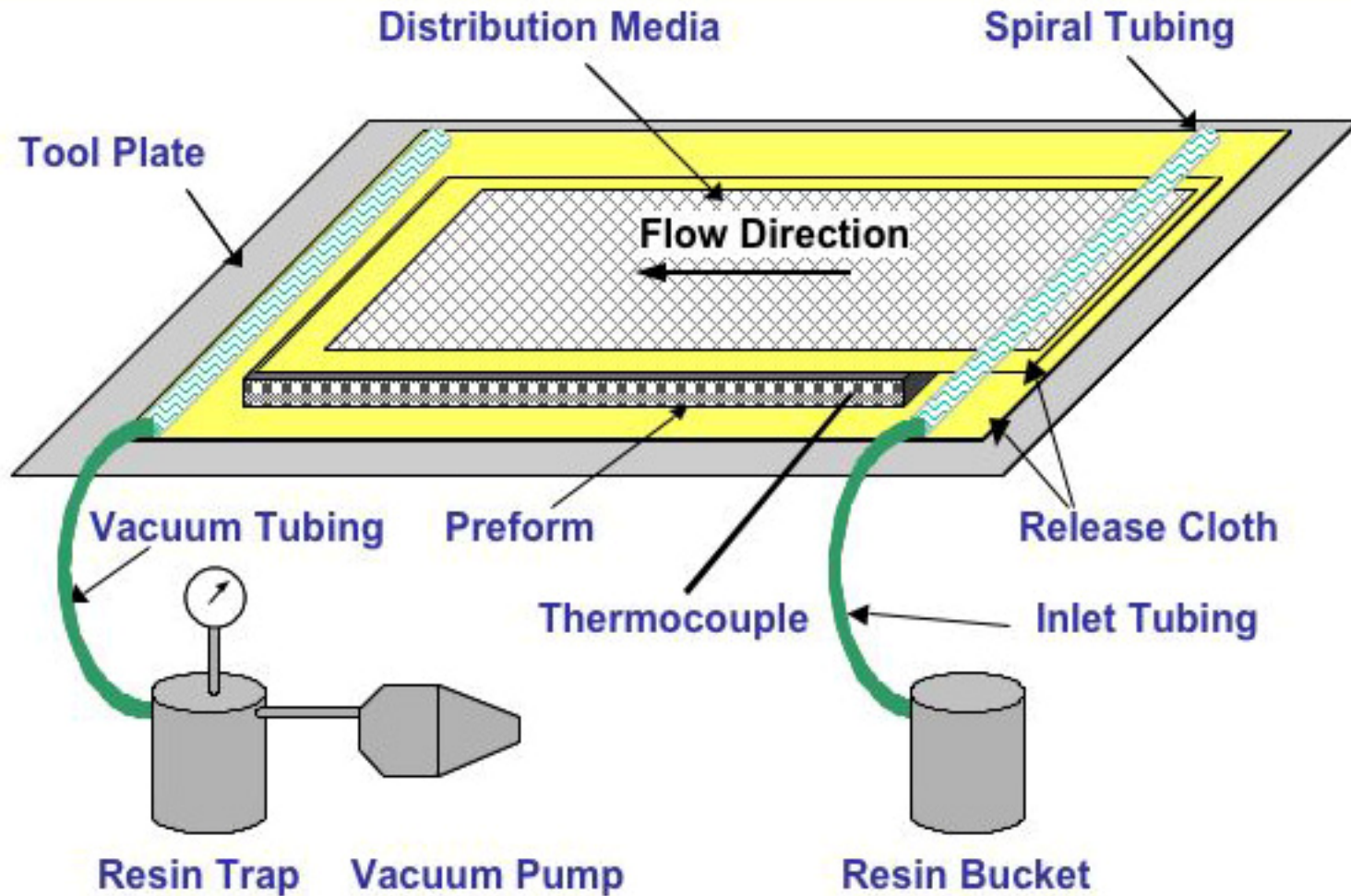


GLARE Characteristics

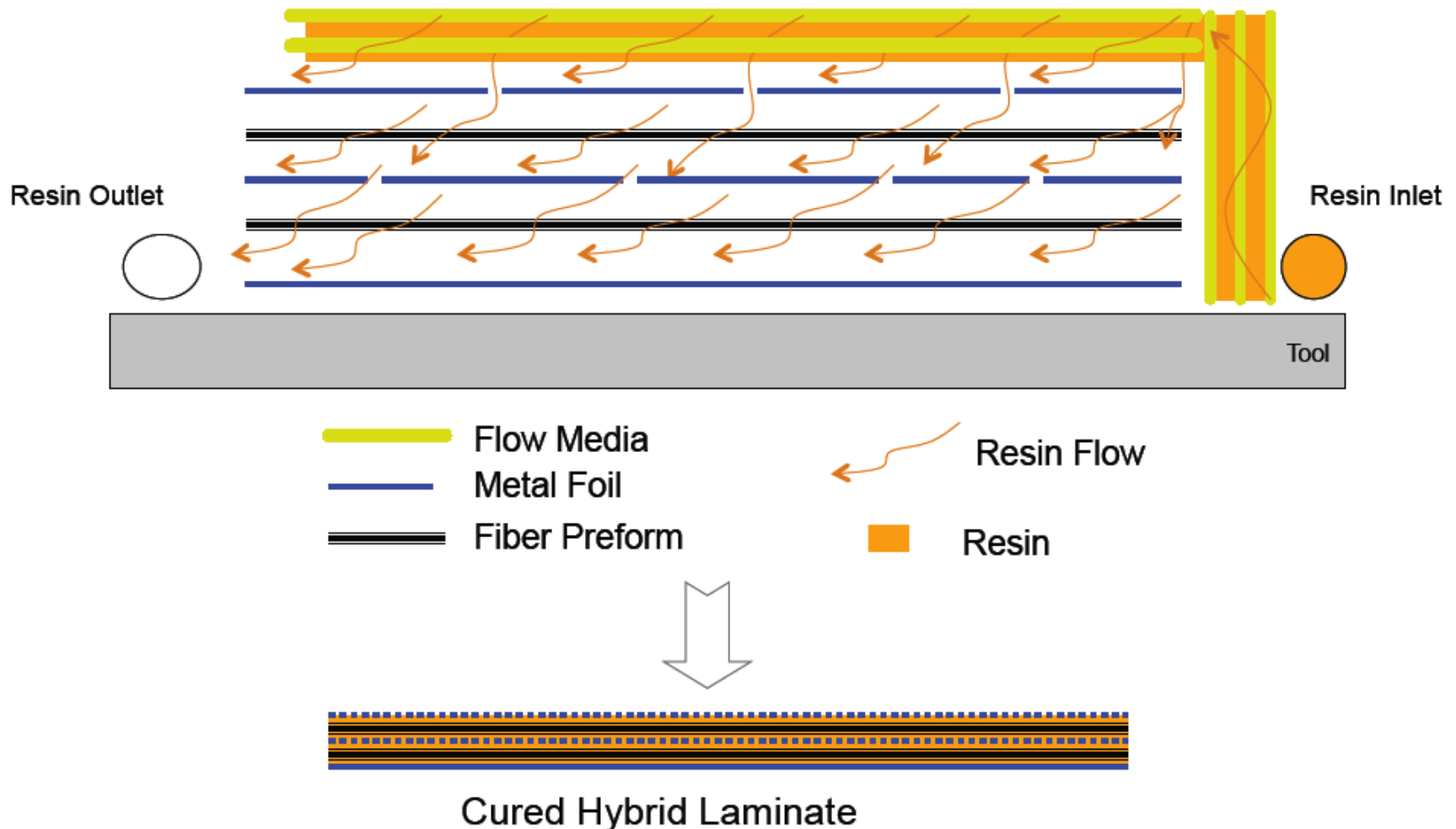
- **Strengths vs. Metal**
 - Increased modulus
 - Improved fatigue resistance
 - Lower weight
- **Strengths vs. Composite**
 - Improved impact resistance and damage tolerance
 - Improved permeation resistance
 - Increased load bearing ability
- **Subsonic use only due to temperature limitations**



VARTM Experimental Setup

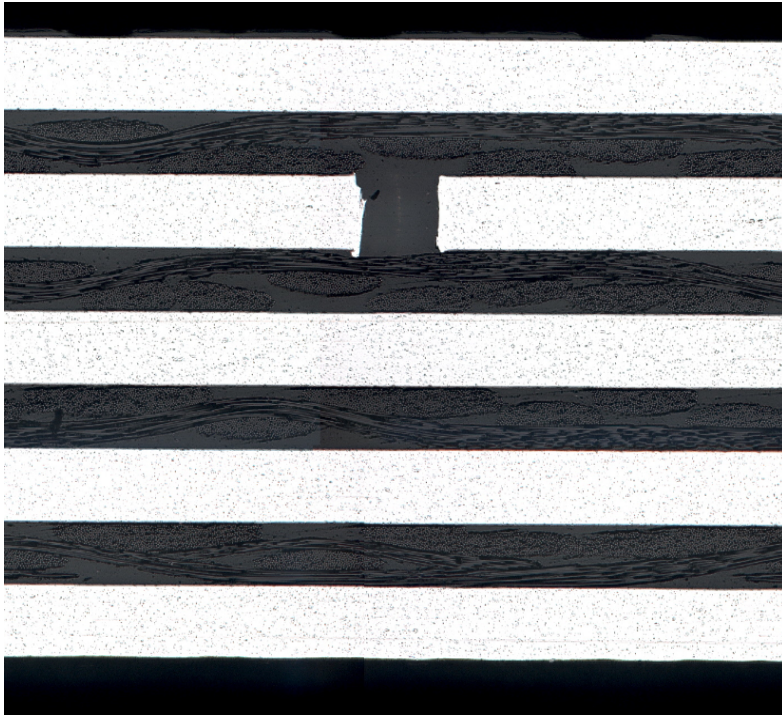


FML VARTM Process

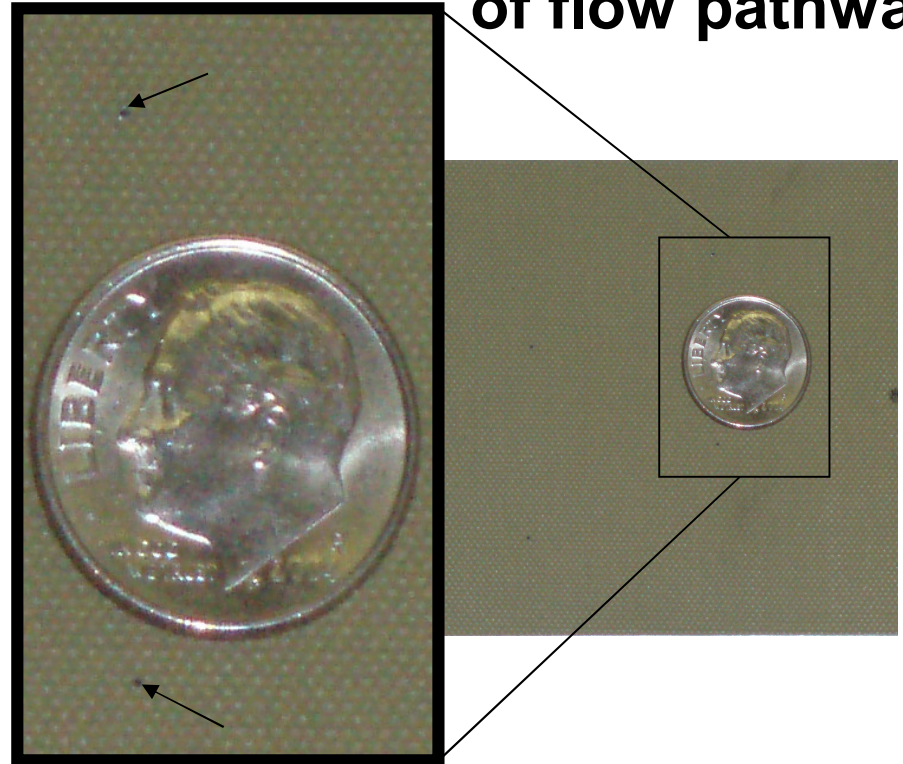


- Effect (+/-) of resin pathways in metal foils in FML

VARTM Processed FML

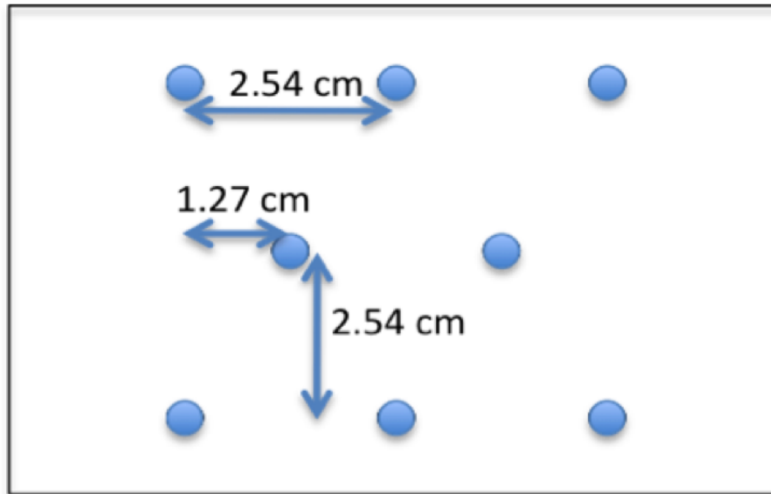


**Photomicrograph of FML
with flow pathway**

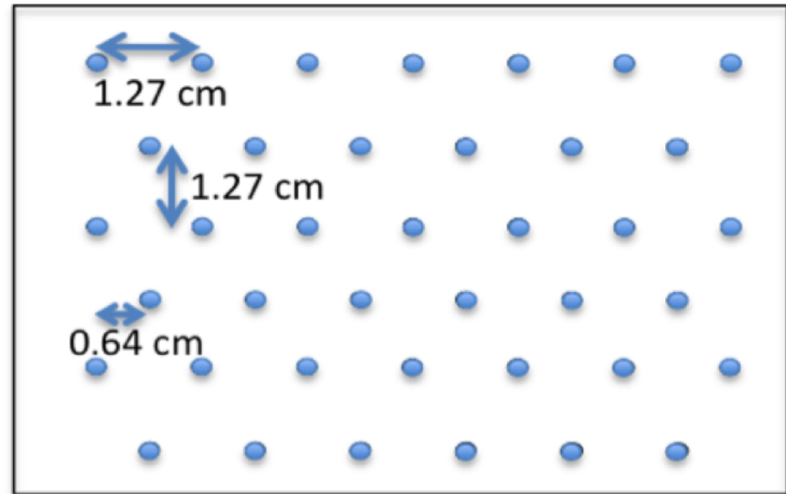


**FML showing size
of flow pathways**

Hole Spacing Patterns/ Lay-Up



Large (2.54 cm) Spacing Hole Pattern



Small (1.27 cm) Spacing Hole Pattern

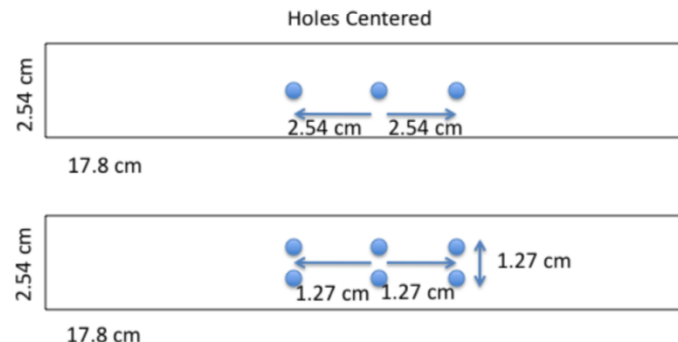
**Treated and primed 2024-T3 Aluminum 0.381 mm thick /
8-HS S-glass fabric FML with a lay up:**

[Al/0° /90° /Al/0° /90° /Al/0° /90° /Al/0° /90° /Al]

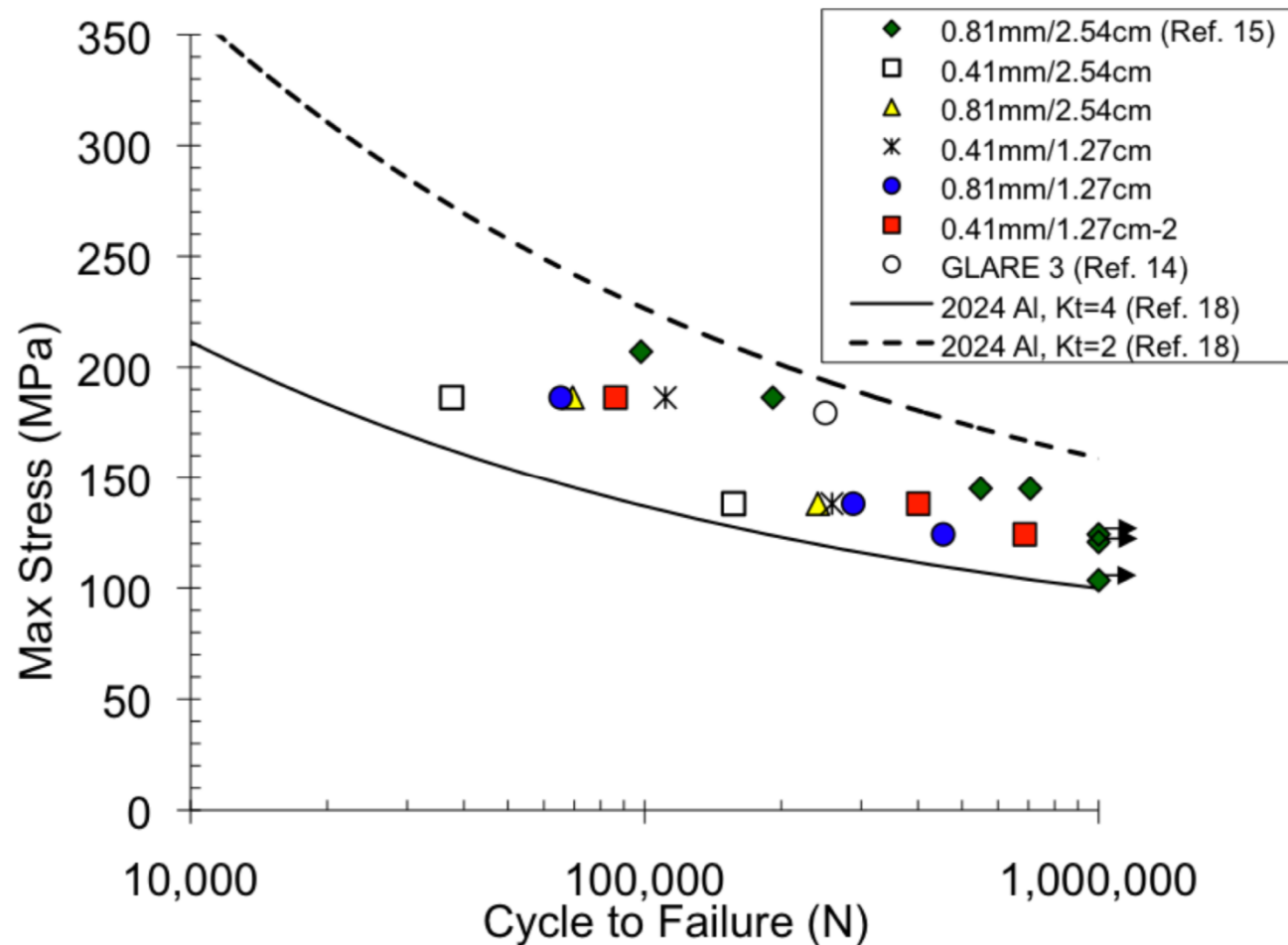
Two part epoxy system, SC-85, Applied Poleramic, Inc.,

Tension-tension Fatigue Data of Aluminum Foils

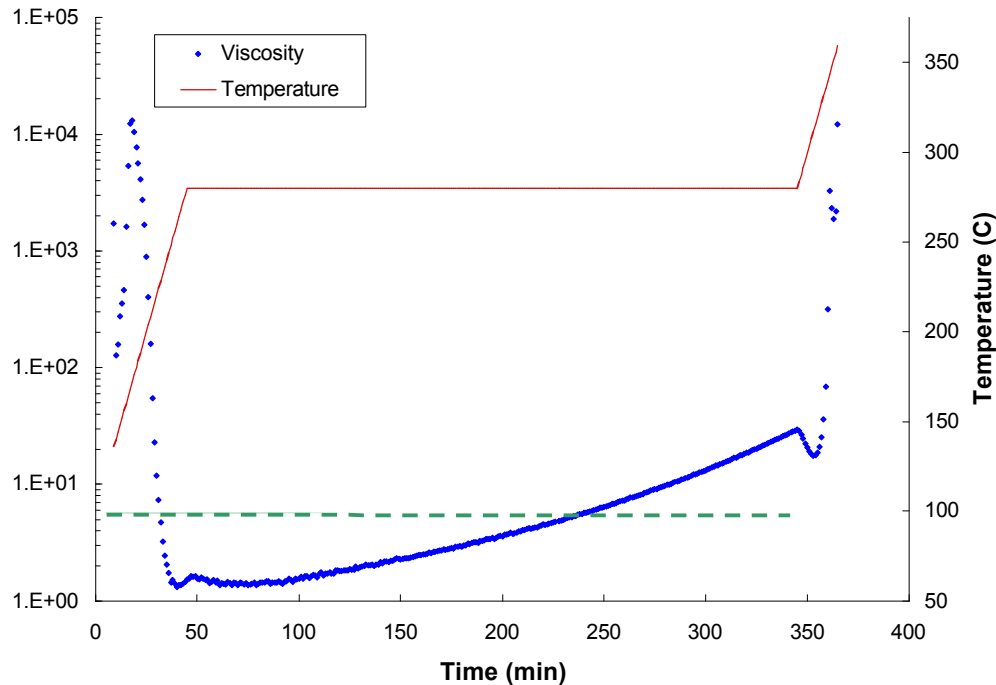
Cycles to Failure @ 241 MPa (35 ksi), R=0.1, 5Hz	No Holes Straight ¹	No Holes Dogbone	0.41 mm Holes, 2.54 cm Spacing, Centered ²	0.41 mm Holes, 1.27 cm Spacing, Centered ²	0.81 mm Holes, 2.54 cm Spacing, Centered ²	0.81mm Holes, 1.27 cm Spacing, Centered ²
Average of 5 Specimens	20983	20551	9801	9645	5230	5879
Standard Deviation	1485	4679	2200	5857	2320	1674



Tension-tension Fatigue Data of Panels Fabricated with Varying Flow Pathway Sizes and Pattern (R=0.1, 10Hz)

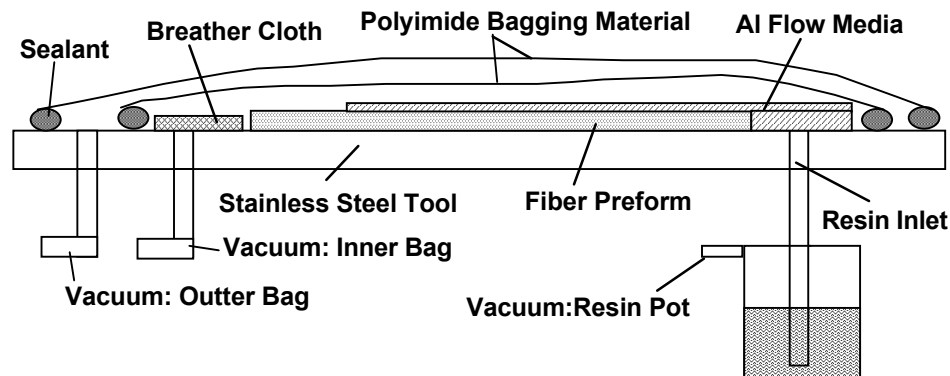


VARTM For High Temperature Composites

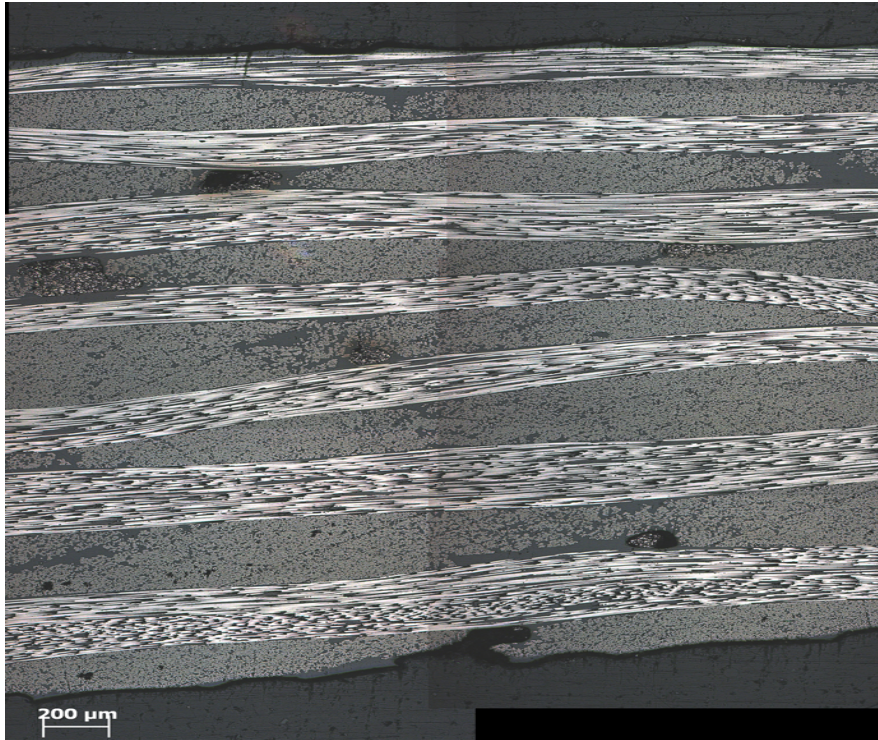


**VARTM Processable
Polyimide Resin
Systems (LaRC™ PETI-8)**

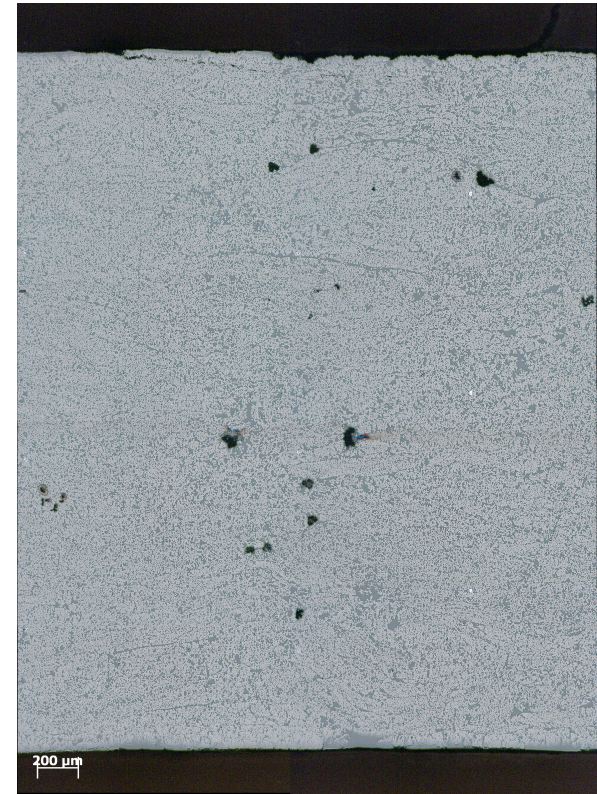
**High Temperature
VARTM Schematic**



Photomicrographs of High Temperature VARTM Panels

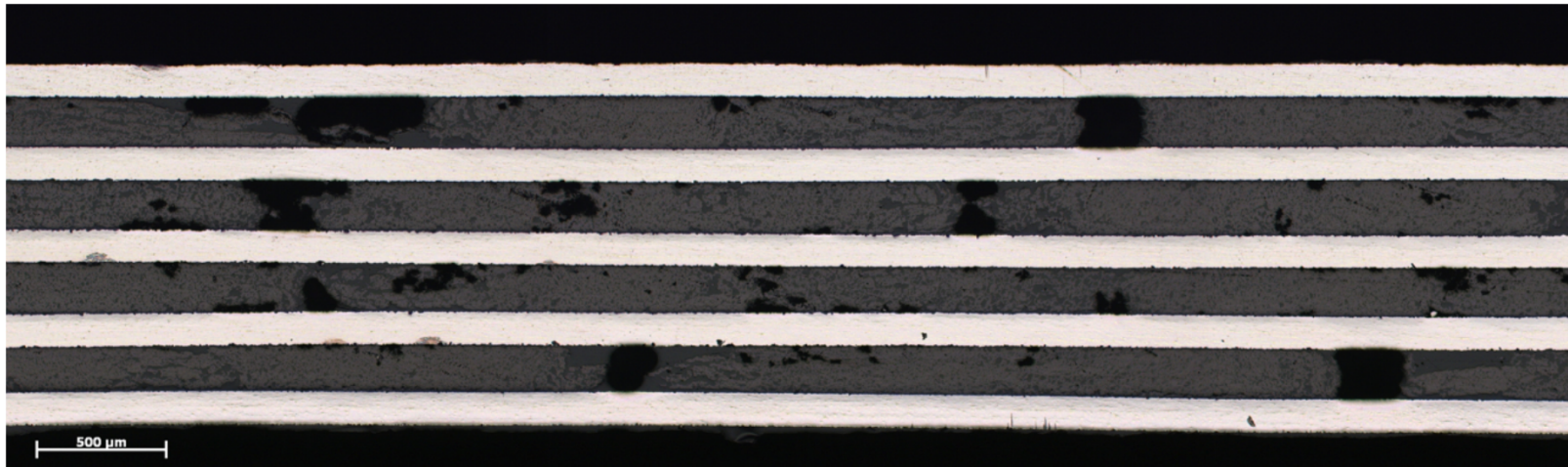


IM7 (5HS) / PETI-330
2.4% Void Volume Fraction
57% Fiber Volume Fraction



IM7 (Uniweave) / PETI-8
1.4% Void Volume Fraction
60% Fiber Volume Fraction

Photomicrograph of LaRC™PETI-8/ IM7/ Ti HT-VARTM Panel



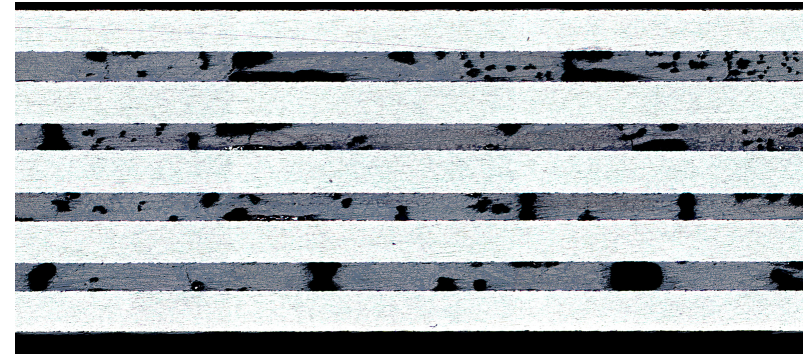
- Titanium/ IM7 uniweave/ PETI-8 FML 15 cm x 15 cm
- 5/4 layup [Ti/0° /Ti/0° /Ti/0° /Ti/0° /Ti]
- 1.27 cm spacing and 0.83 mm hole pattern
- 0.127 mm thick Ti-15-3-3-3 (Pasa-Jell™ 107)

Fatigue Data of Titanium Foils with Various Holes Sizes and Patterns

Cycles to Failure @ 345 MPa (50 ksi)	No Holes	0.41 mm Holes, 2.54 cm Spacing, Centered¹	0.41 mm Holes, 1.27 cm Spacing, Centered¹	0.41 mm Holes, 1.27 cm Hole Pattern²	0.83 mm Holes, 2.54 cm Spacing, Centered¹	0.83 mm Holes, 1.27 cm Spacing, Centered¹
Average	73405	55511	47355	30884	38783	53451
Standard Deviation	17079	14091	10467	13179	24954	8516

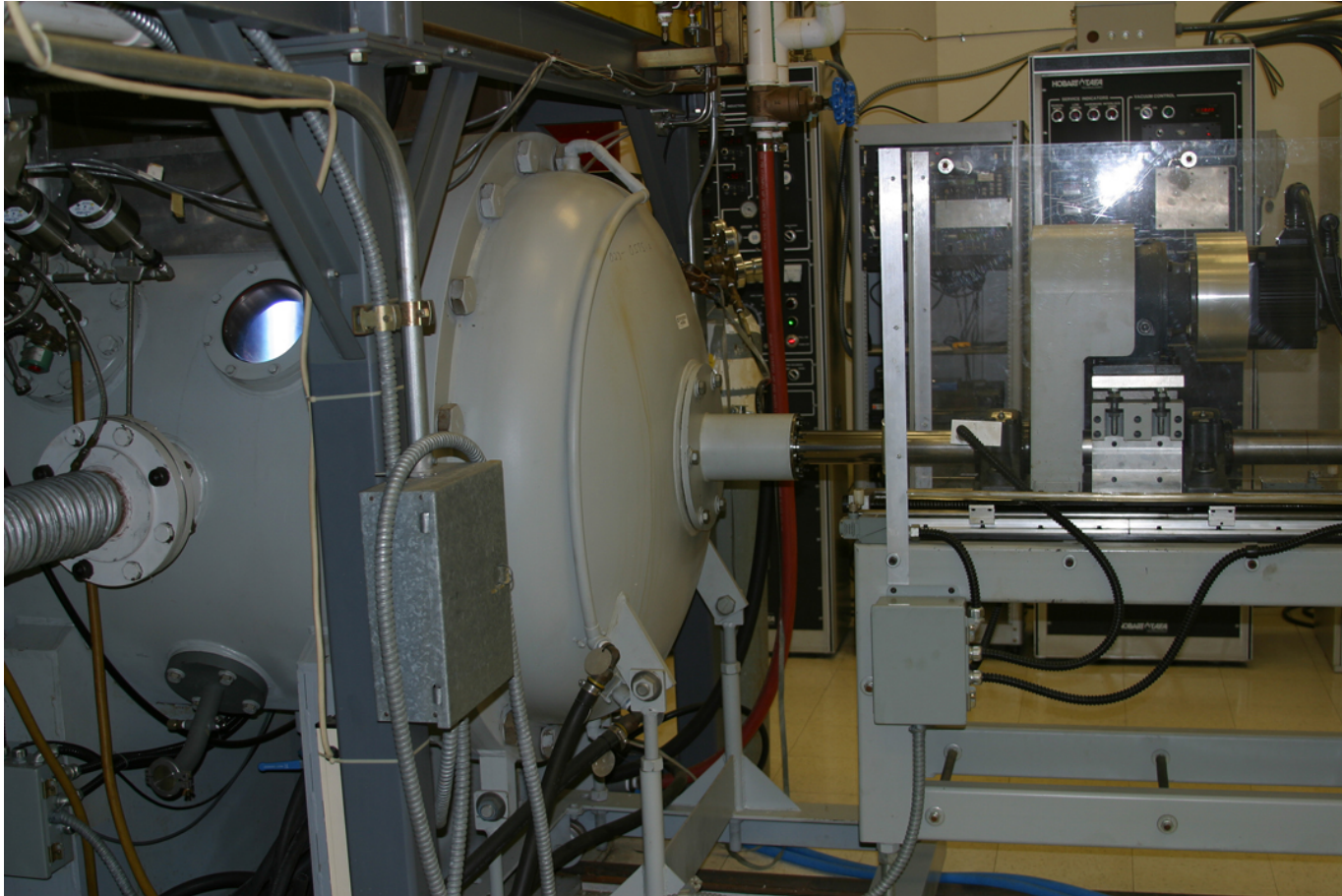


5/4 Titanium/ IM7-12k Uniweave/ LaRC™ PETI-8 FML

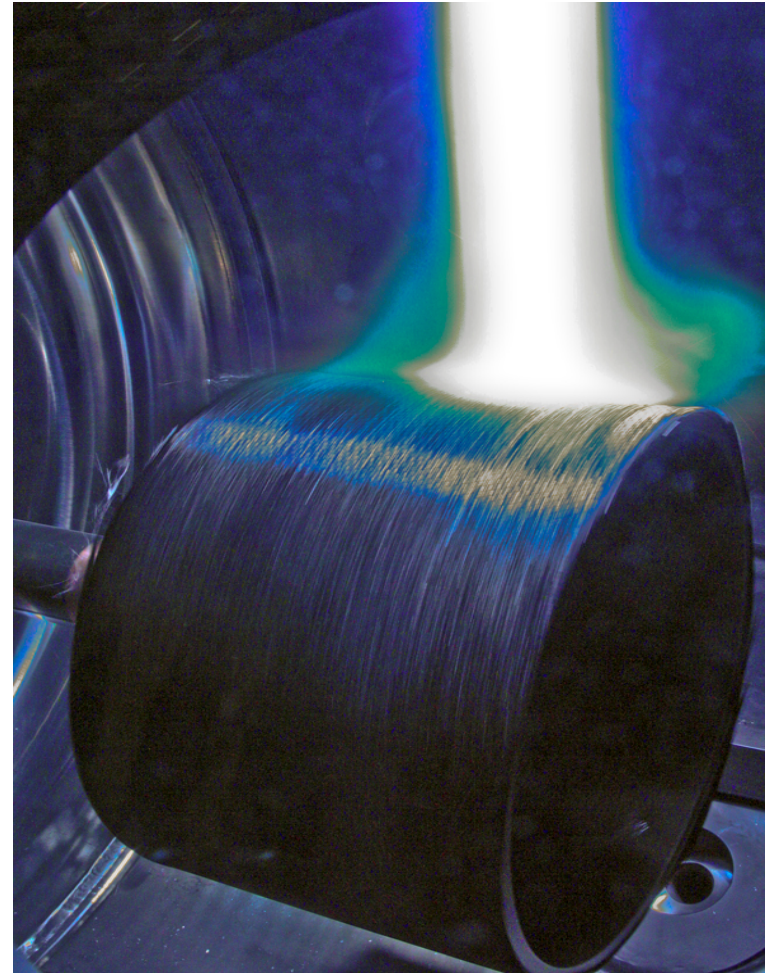
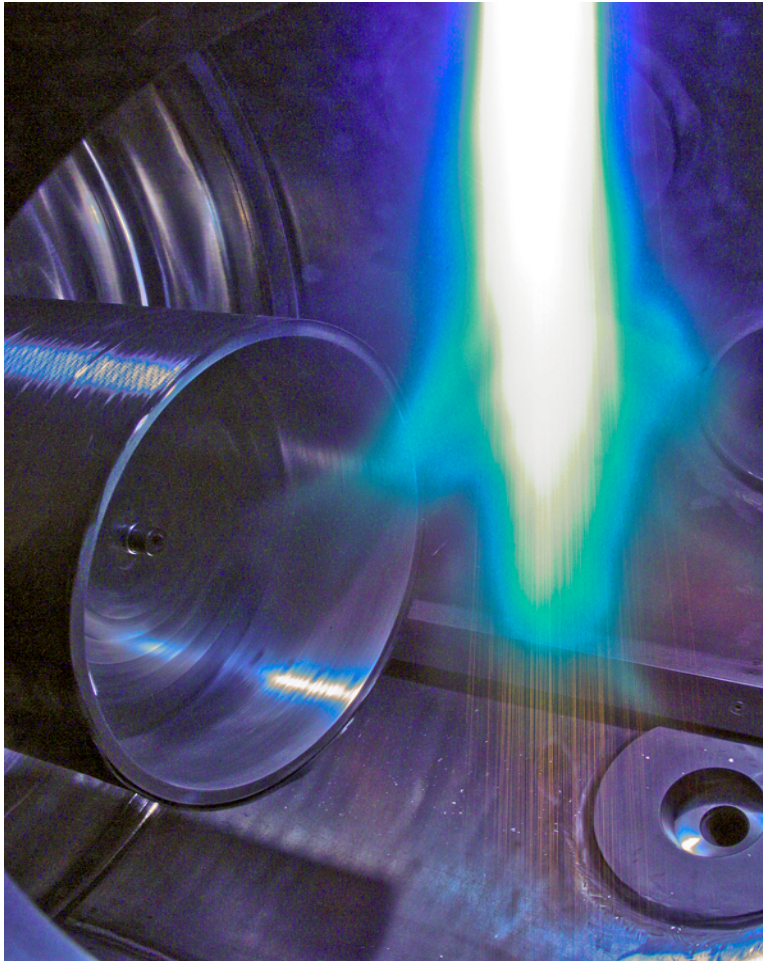


- Titanium/ IM7 uniweave/ PETI-8 FML 20 cm x 25 cm
- 5/4 layup [Ti/0° /Ti/0° /Ti/0° /Ti/0° /Ti]
- 1.27 cm spacing pattern and 0.41 mm holes
- 0.406 mm thick Ti-6-4 (Pasa-Jell™ 107)

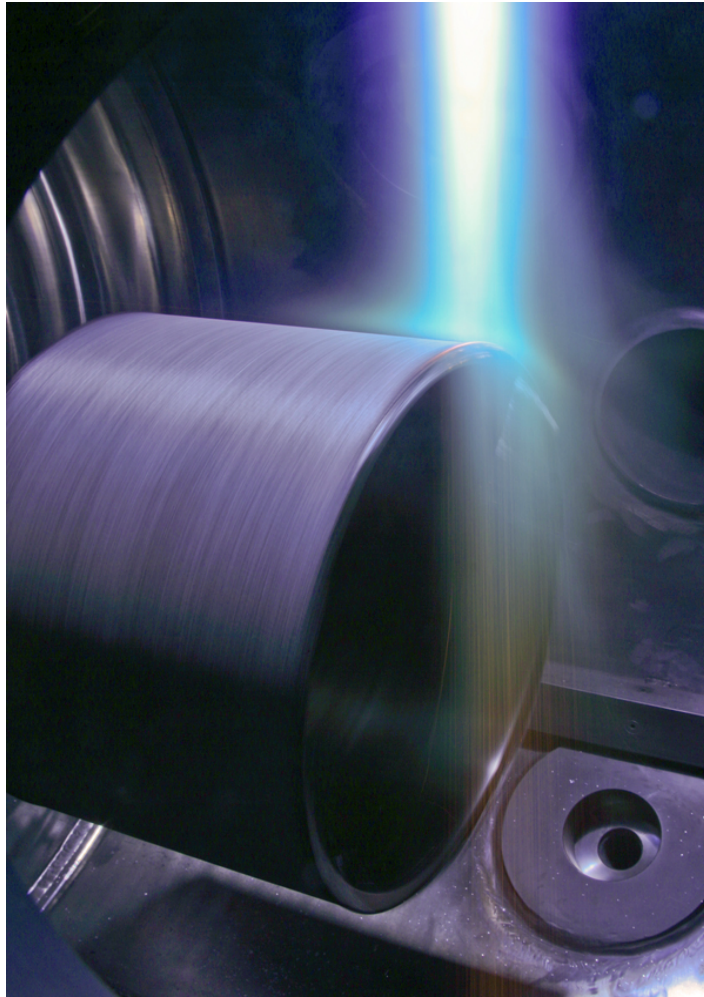
Plasma Metal Deposition Equipment



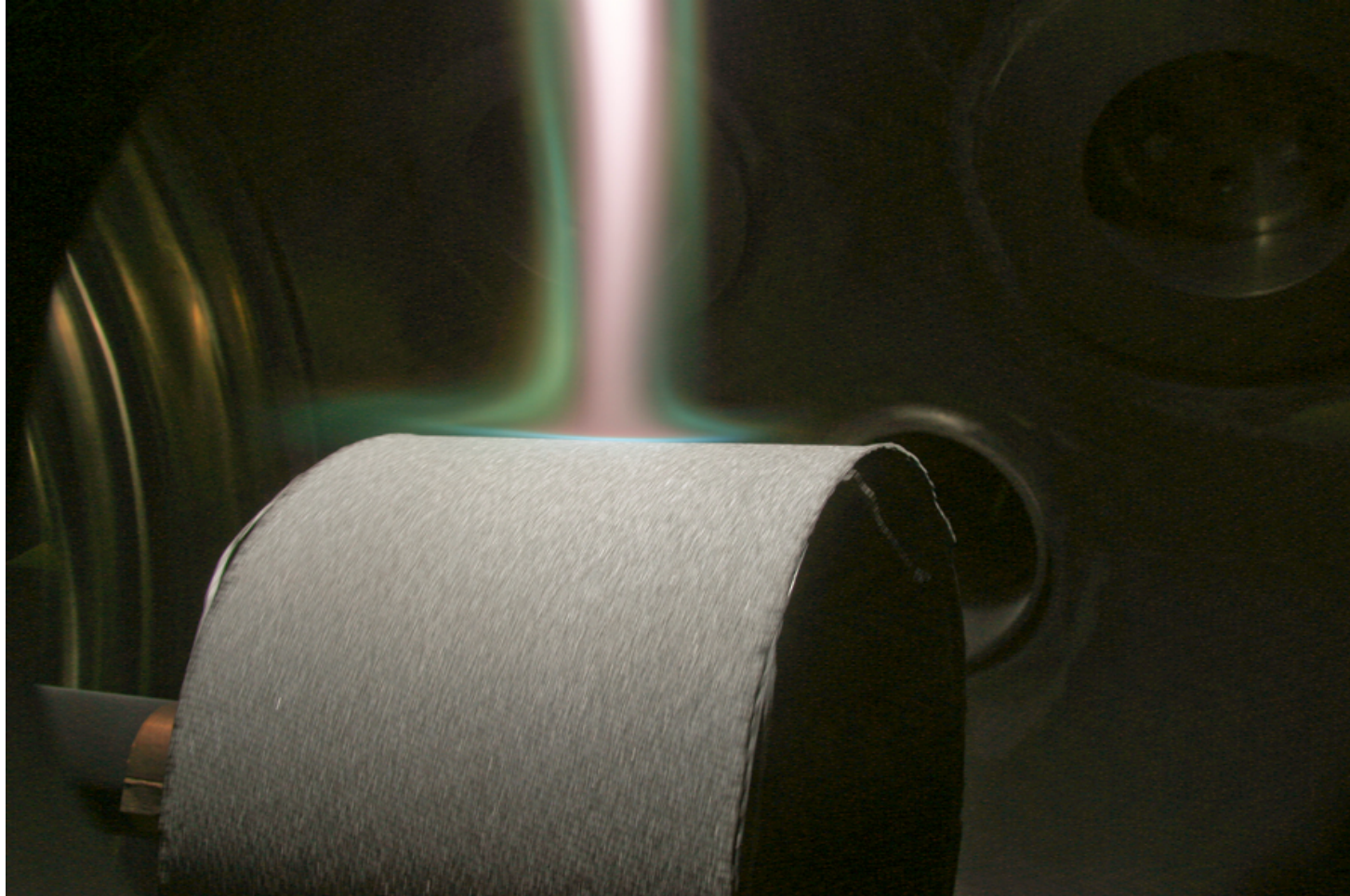
Plasma Metal Deposition Process



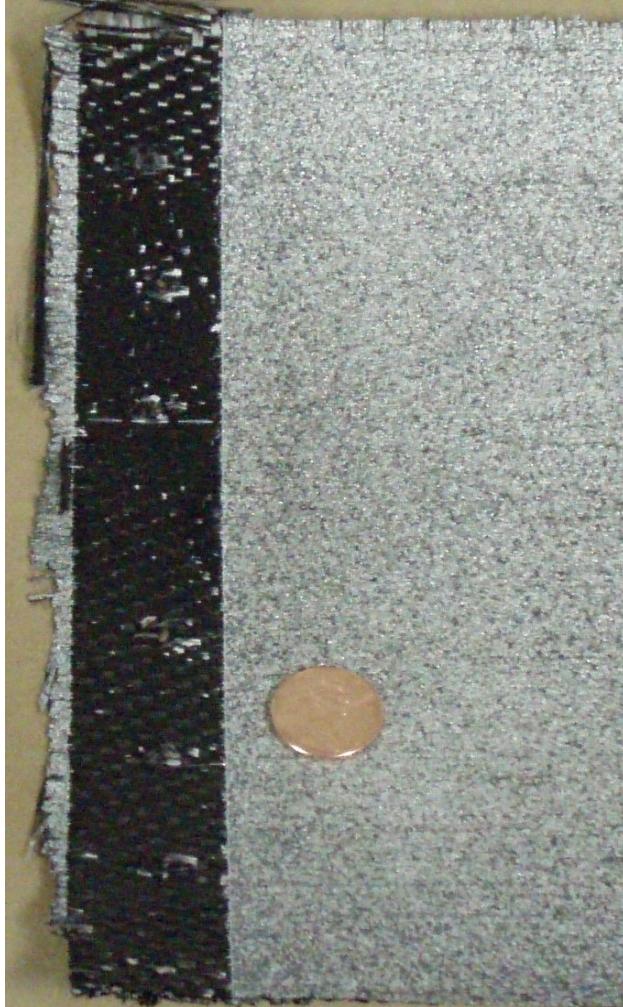
Plasma Metal Deposition Process



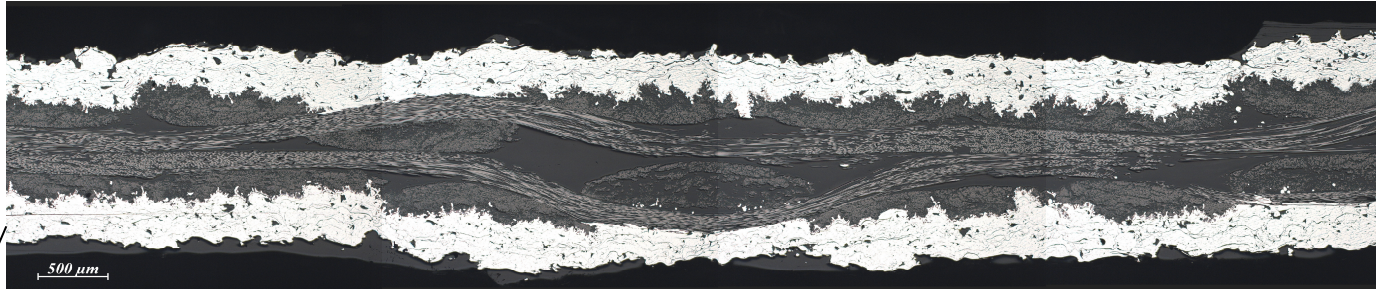
Plasma Metal Deposition Process



Plasma Metal Coated Fabrics

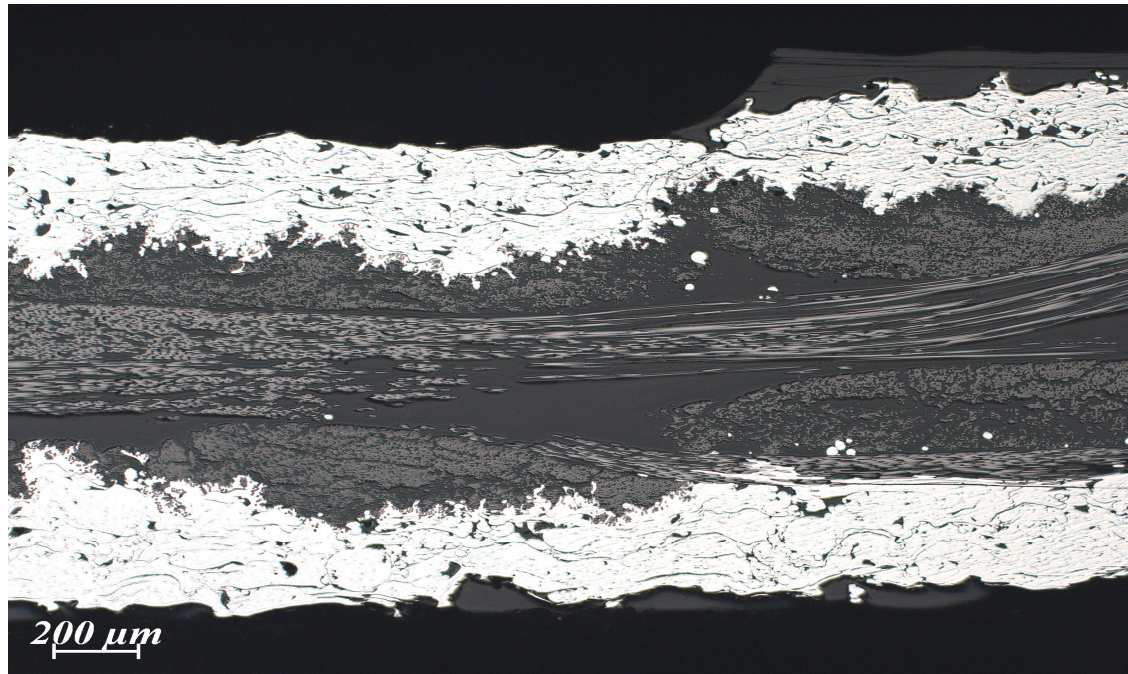


Photomicrograph of Plasma Metal Coated Fabric

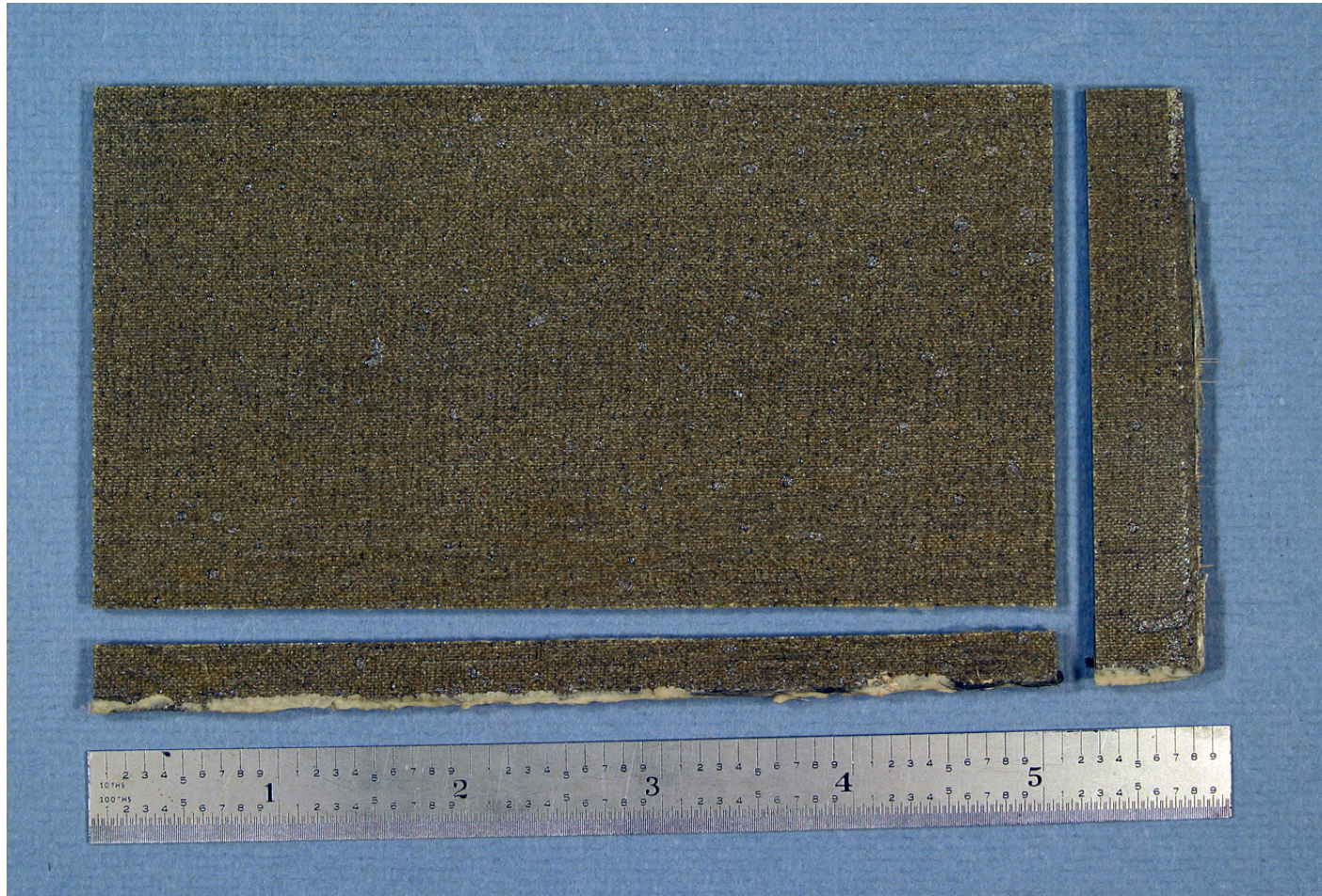


Metal

Fabric



Plasma Metal Coated VARTM Infused Laminate



Tailorability of VARTM Processed FMLs

Materials

- **Fibers: Glass, Carbon, Others**
- **Resins: Epoxy, Polyimide, Others**
- **Metals: Aluminum, Titanium, Copper, Others**

Process

- **Resin Pathways (size, pattern, etc.)**
- **Plasma Coated Metal Layers (thickness, texture, single/double sided, permeability, etc.)**

Laminate

- **Stacking Sequences/Number of Plies**
- **Metal/Composite Ratios**
- **Fabric Preform Types**



Conclusions

- Demonstrated the feasibility of fabricating FML by a VARTM infusion process.
- Epoxy/Glass/Al VARTMFML has been successfully refined to consistently produce high quality panels with good mechanical properties.
- Further optimization, (how the resin pathways are introduced, improving hole edge quality), could further improve the process and resultant properties.
- The NASA developed LARC™ PETI-8 resin system was successfully infused via VARTM into a titanium foil/IM7 FML.
- Further enhancements of process conditions are required to optimize the VARTMFML quality for high-temperature fiber metal laminates.
- Developed VARTMFML with plasma deposited metal on various fabrics followed by resin infusion.



