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Automotive Defense Aerospace Transportation Sports gear

Evaluation of joining techniques for continuous fiber reinforced thermoplastic composites

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2008 ACCE Conference
16–18 September 2008

Outdoor products Footwear Consumer electronics Medical

Outline

- Fiberforge overview
  - Company
  - Process
- Thermoplastic composite joining
  - Joining Method Evaluation
  - Application Review

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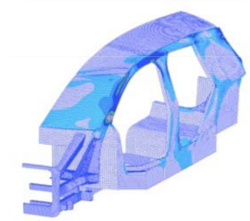
Fiberforge® is a private technology company whose specialty is thermoplastic advanced composite production technology.

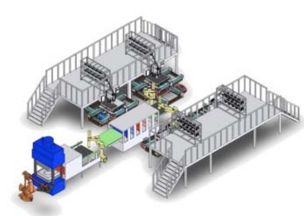


Our mission: To be the leading global provider of cost-effective solutions for manufacturinghigh-performance thermoplastic composite products.

Fiberforge's Relay™ Station — A patented, automated process that enables cost-effective production of thermoplastic advanced composites in high-performance applications.

Complete product offering from research to production to technology transfer.

Diverse customer base includes world leading companies in aerospace, automotive, consumer electronics, sporting goods, medical, and military markets.



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Why Thermoplastics?

Superior Properties & Performance
- Excellent toughness
- High energy absorption
- Recyclable
- Low VOC emissions
- Infinite shelf life
- Low cost
- Excellent flame, smoke, and toxicity performance

Cost Efficient Fabrication
- High speed automated lay-up
- Rapid processing for high volumes
- Press moldable / stampable
- Reformable
- Weldable
- Can be overmolded

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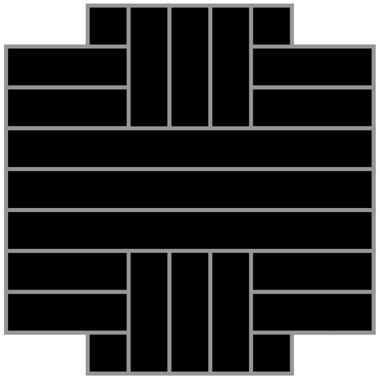
Fiberforge process overview

Unidirectional Tape



Tailored Blank made by Relay Station

Consolidate Tailored Blank into Solid Laminate

Thermoformed 3D Part

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Fiberforge Relay Station

Relay™ Station: A patented process for manufacturing a 2D, near net shape preform called a Tailored™ Blank

RELAY

- Rapid
- Efficient
- Lay Up

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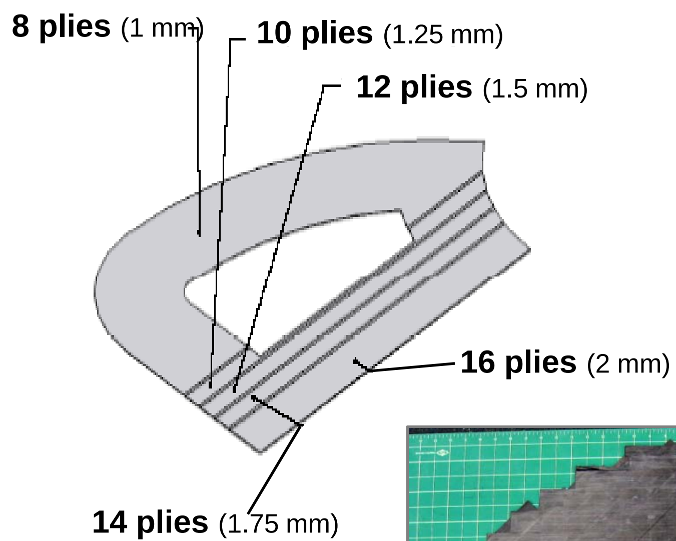
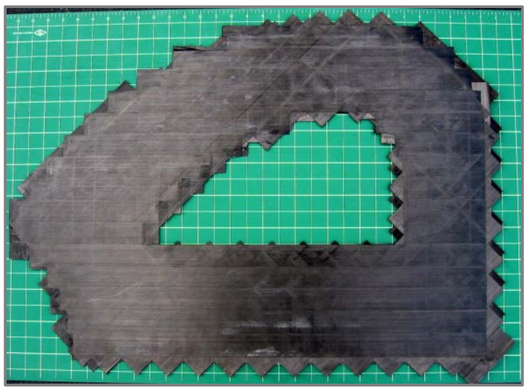
Tailored Blanks

What is a Tailored Blank?

- Flat, multi-ply laminate made from multiple layers of fiber and resin tape.
- Precise fiber orientation in each ply; variable thickness throughout ply if needed.
- Fiber orientation is tailored to part-specific loading.
- Multiple fiber types and volume fractions possible within part.
- Part shape tailored to part geometry.
- Issued Patents #6,607,626, 6,939,423, 1155466C (China), other patents pending



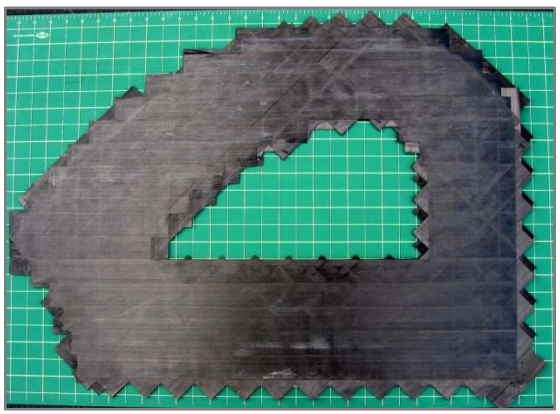


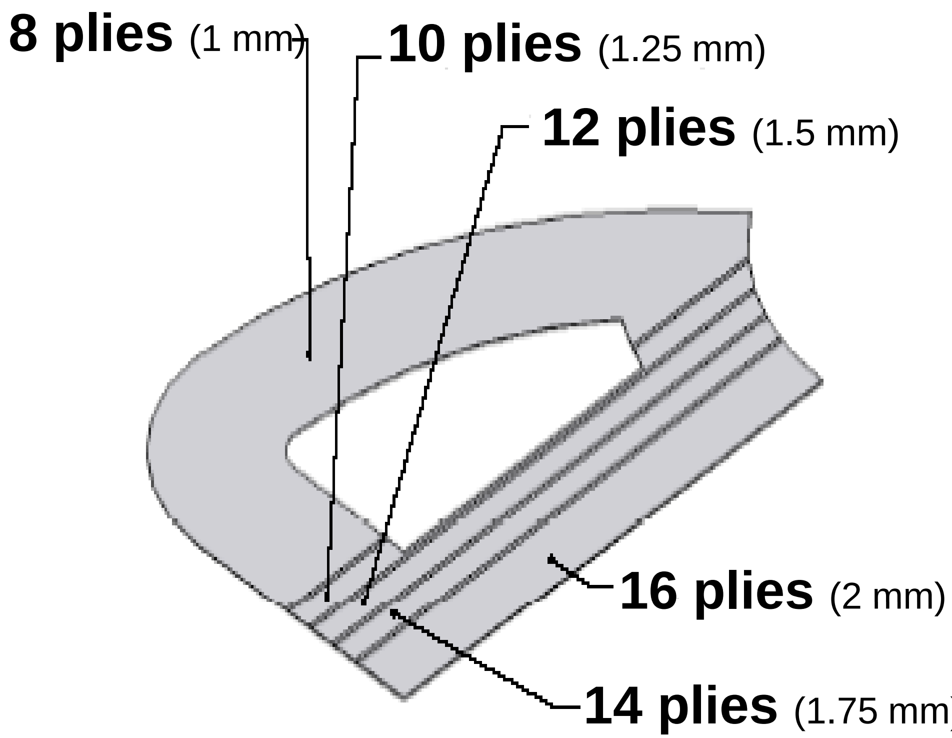
Result:

Lower Scrap • Faster Production

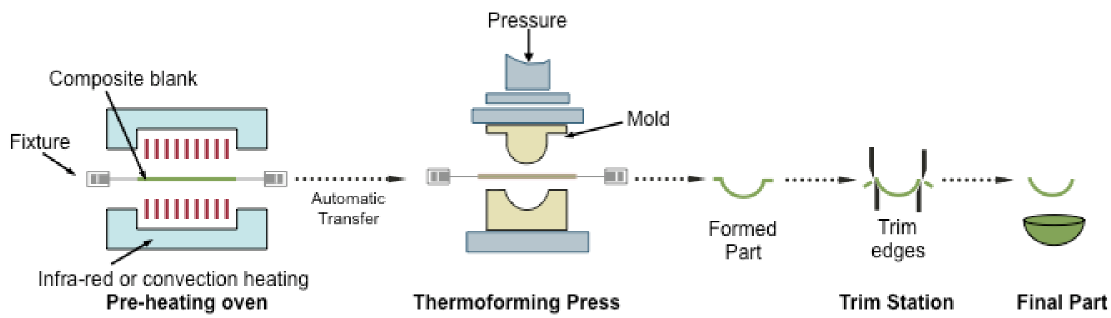
Less Labor • Lower Cost

Tailored Blanks: Optimal Material Usage and Part Performance

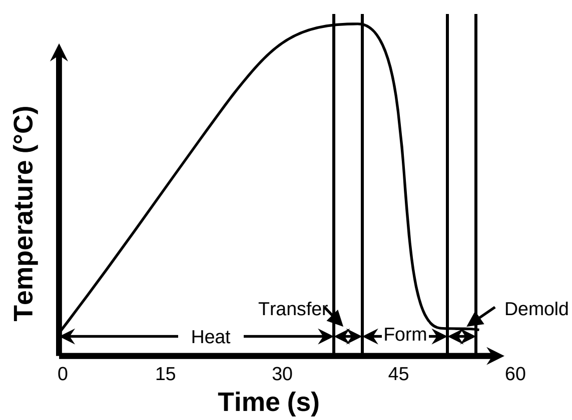


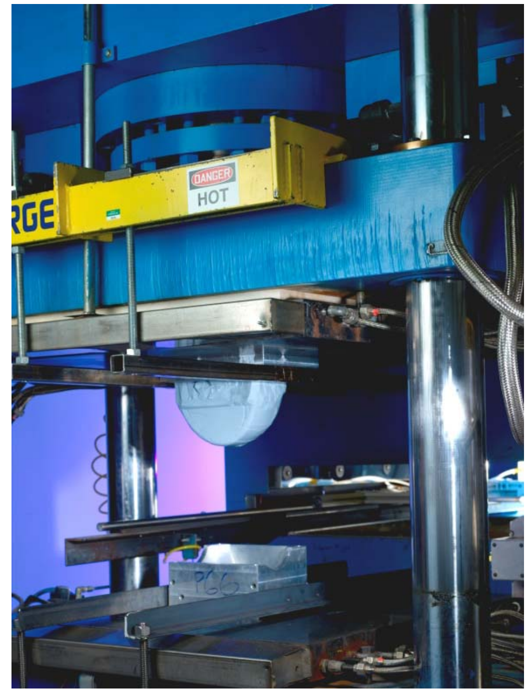


Thermoforming



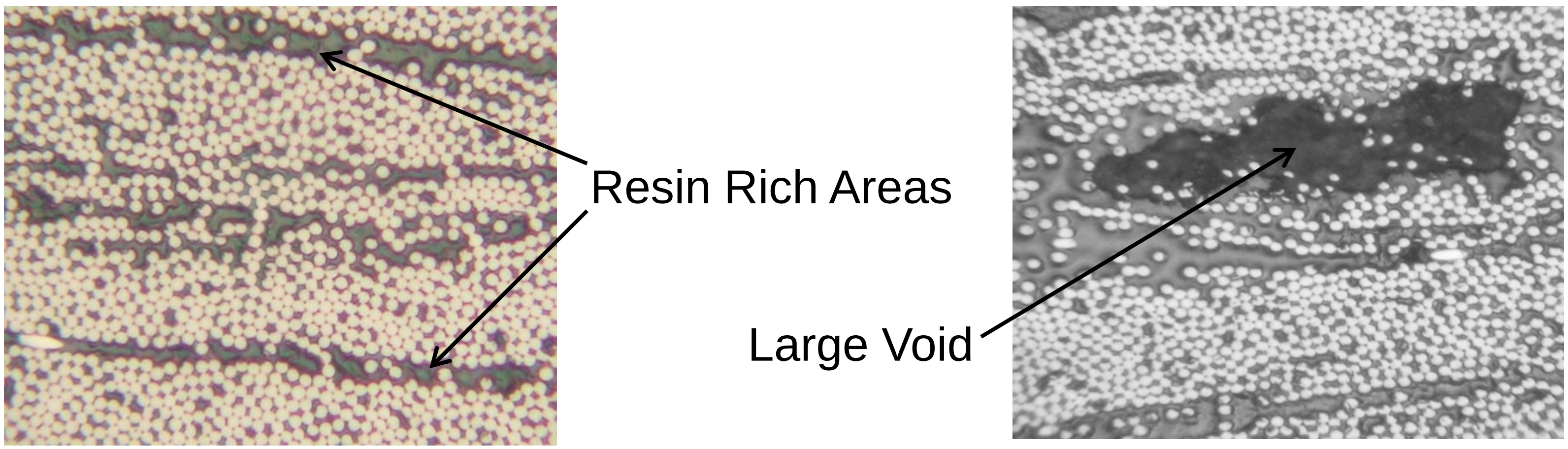
- Load blank into shuttle system
- Heat in infrared oven
- Shuttle into press
- Close press to form and “freeze” part





Void Content with FF Process

- The quality and performance of thermoplastic composites is determined by void content
- Void content is minimized by the optimization of process parameters
- Fiberforge aims to have approximately<2% void content after forming



Low Void Content Micrograph Example

High Void Content Micrograph Example

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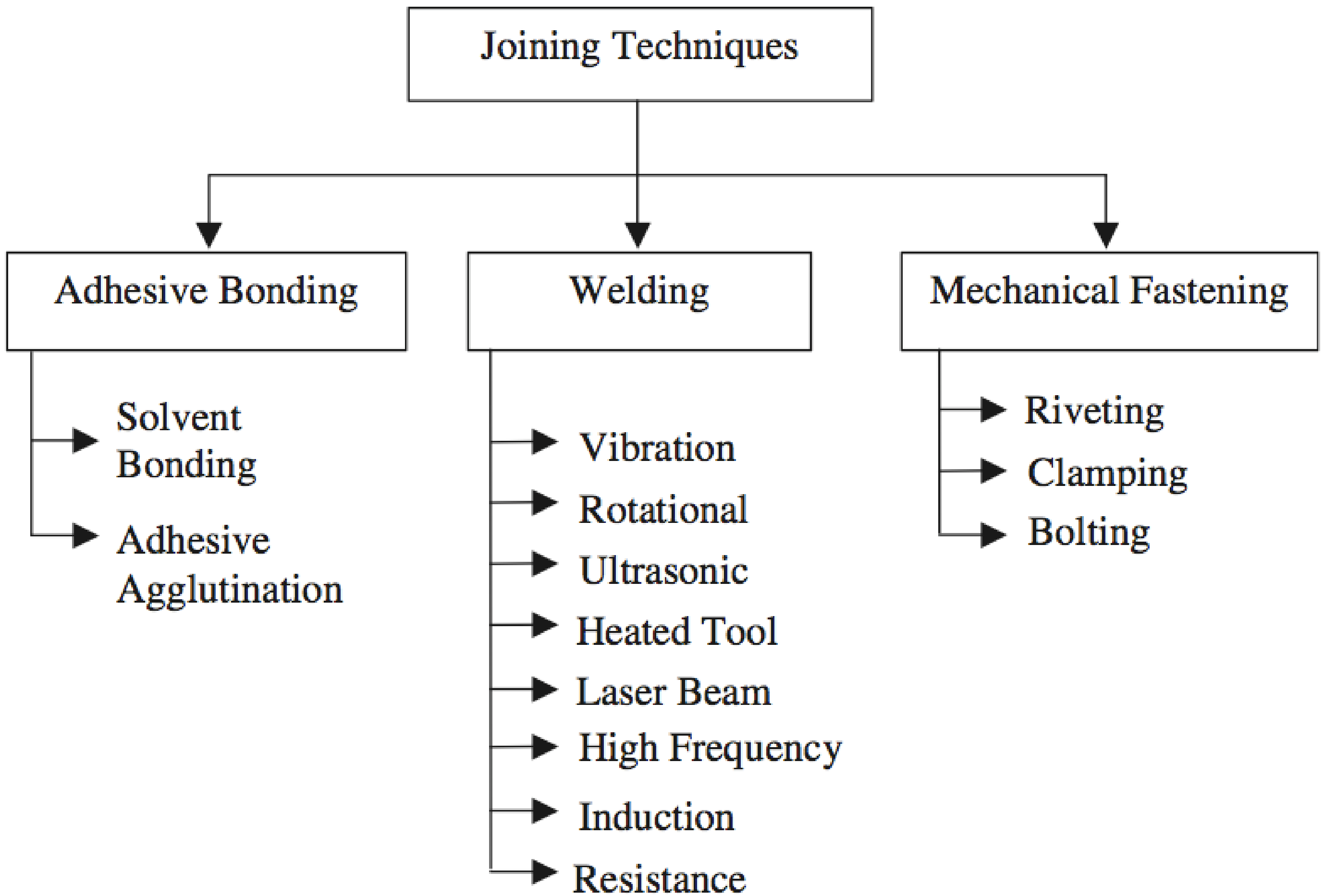
Joining of Thermoplastic Parts

Method Evaluation

Joining options for thermoplastic composites



Source: CRC

Joint design considerations

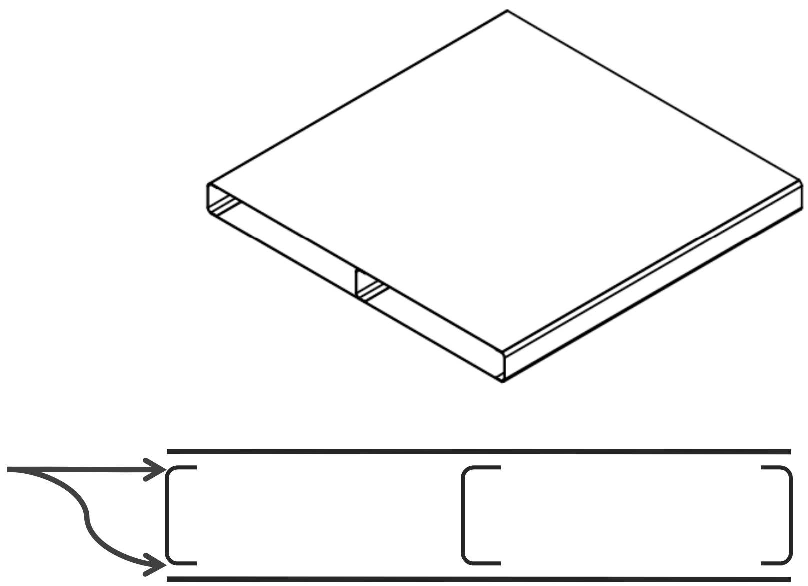
- Materials being joined
- Load requirements (shear, peel, fatigue, etc.)
- Bond length
- Number of bonds per part
- Bond strength to meet weight and load requirements
- Environmental resistance (fuel, salt water, service temperature, etc.)
- Bond verification: NDI/proof testing
- Compatibility with part geometry

Joining method evaluation matrix

	Load requirements	Fatigue	Bond length	Reliability	Environ. resistance	NDI compatible	Compatible with part geometry	Compatible with materials	Weight	Similar Applications
Adhesives										
Mechanical fasteners										
Thermal										
Vibration										
Ultrasonic										
Resistance										
Induction, no susceptor										
Induction w/susceptor										

+ = positive 0 = neutral	- = negative blank = TBD

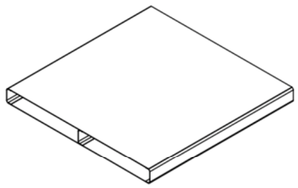
Case Study:
C-channel sandwich panel



Bond of stringers to face sheets

Material: AS4 carbon fiber/PEEK, *59% Vf*

Overview of Joining Methods

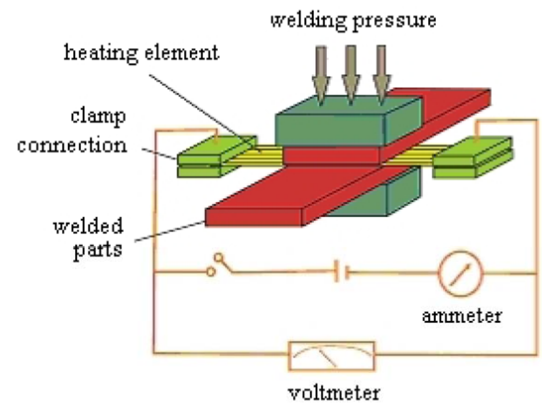


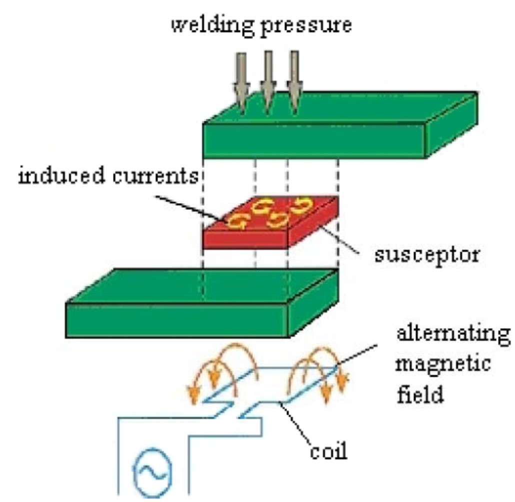
	Load requirements	Fatigue	Bond length	Reliability	Environ. resistance	NDI compatible	Compatible with part geometry	Compatible with materials	Weight	Similar Applications
Adhesives	–	–	+	+	–	0	+	+	0	–
Mechanical fasteners	–	–	+	+	0	+	–	–	–	–
Thermal			+	0	+		0	0	+	–
Vibration	+	+	+	0	+		–		+	
Ultrasonic	–		–	–	+		–		+	
Resistance	+		+		0		+	+	0	+
Induction, no susceptor	+		+	+	+		+	+	+	+
Induction w/susceptor	+		+	+	0		+		0	+

+ = positive 0 = neutral	- = negative blank = TBD

Resistance and Induction Welding

- Resistance Welding
  - Uses an electrically resistive implant sandwiched between the bonding surfaces of the laminates. This provides the necessary heat to the joint.
  - Simple method with simple tooling and little surface treatment required
- Induction Welding
  - A coil is used to generate an alternating magnetic field that induces eddy currents in the joint material.
  - Heat is then produced due to the resistance properties of the material.





Source: AIAA

Development approach

Literature search → Lap shear trials → Parameter optimization → Scale up and hardware demonstration

Induction welding

- Collaboration with University of Delaware Center for Composite Materials,Dr. Shridhar Yarlagadda and Dr. John Gillespie

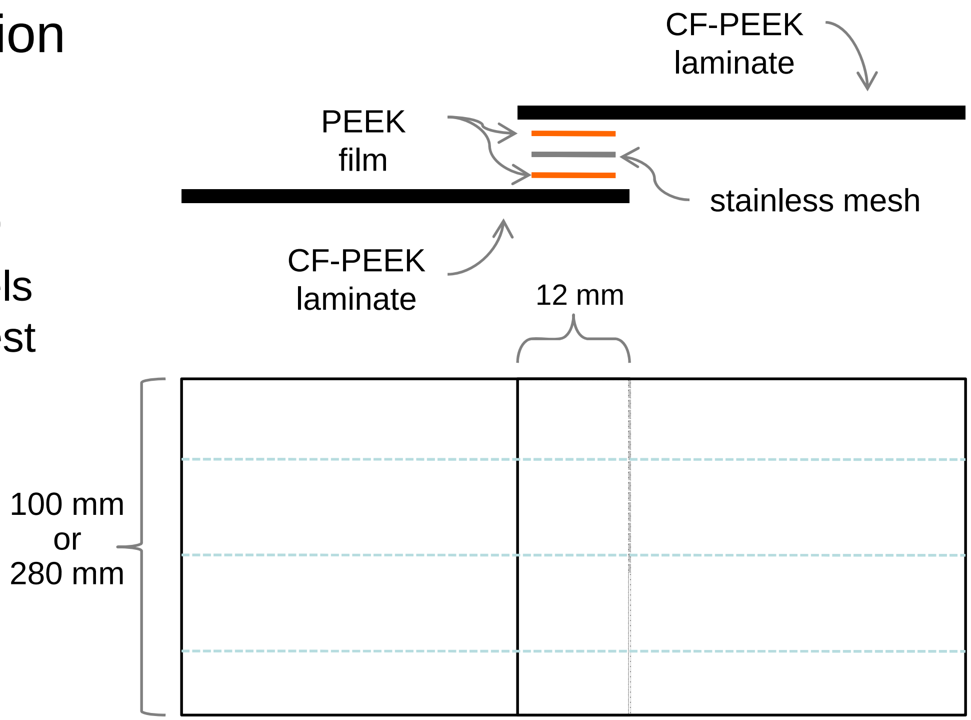
Resistance welding

- Development performed internally within Fiberforge

Resistance Welding Trials

- HP 6268 DC Power Supply
  - Maximum output of 40V and 30A
  - Analog display
  - Self-cooling

- Lap shear specimen construction
  - CF-PEEK laminates
  - PEEK film 0.12 mm
  - Stainless Steel mesh, 400 x 400
  - 100 mm and 280 mm wide panels fabricated and cut into 25 mm test specimens



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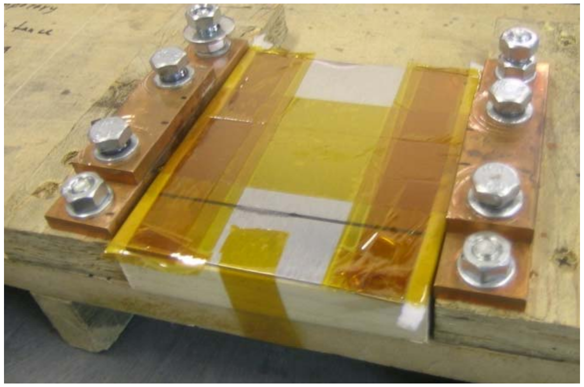
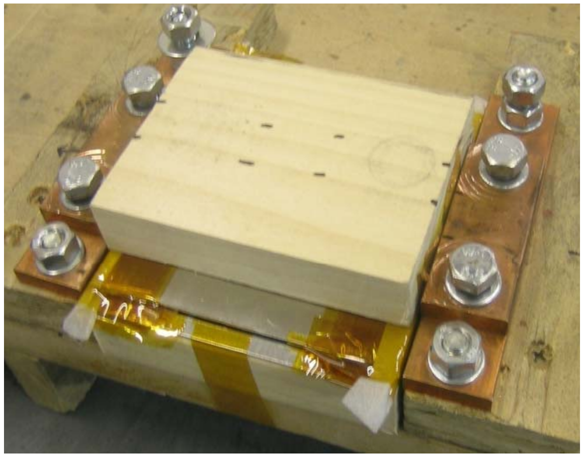
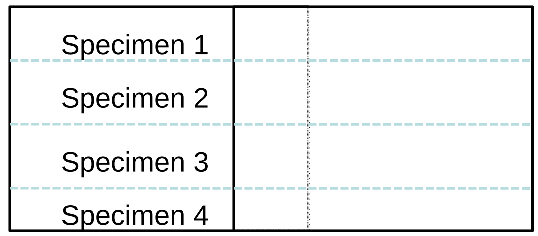
Coupon welding

- Lap shear specimen is sandwiched between two steel caul sheets and covered by insulating blocks
- Clamps used to apply 0.6 MPa pressure on the weld
- Two cool streams of air were directed at the edges of the weld in order to cool the mesh and extend the processing window





Coupon welding results



	Peak Force	Stress
Specimen 1	8.6kN	17.0MPa
Specimen 2	13.3kN	28.9MPa
Specimen 3	12.3kN	30.6MPa
Specimen 4	10.9kN	24.3MPa

Overheating of the edges of the weld where the mesh was exposed to air caused degradation of the material. Degraded carbon/PEEK composites became more brittle and thus broke at lower forces.

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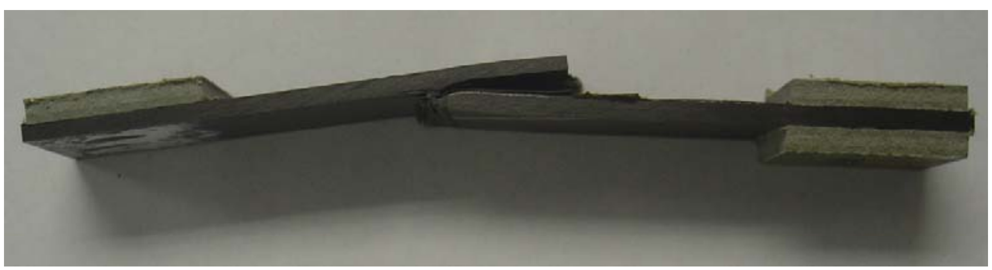
Weld failure

- Adhesive failure occurred on the edges
- Cohesive failure occurred in the middle specimens



Lap Shear Preliminary Test Results

	Adhesive bonding baseline	Induction Welding (UD)	Resistance Welding (FF)
Lap Shear Strength – MPa (psi)	17 (2,465)	26.7 (3,872)	27.7 (4,017)
Standard Deviation	2.3	6.4	7.4

Summary & conclusions

- Framework established for evaluating joining methods
- Two fusion bonding methods evaluated and preliminary lap shear testing performed
- Induction welding and resistance welding showing similar lap shear strengths, both greater than adhesive results
- During process optimization, strengths expected to increase
- Next steps include optimization and scale up to create full-size panel

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Thank You

Acknowledgements

University of Delaware

Dr. Shridhar Yarlagadda

Dr. John Gillespie

Fiberforge

Dan Kaliberov

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