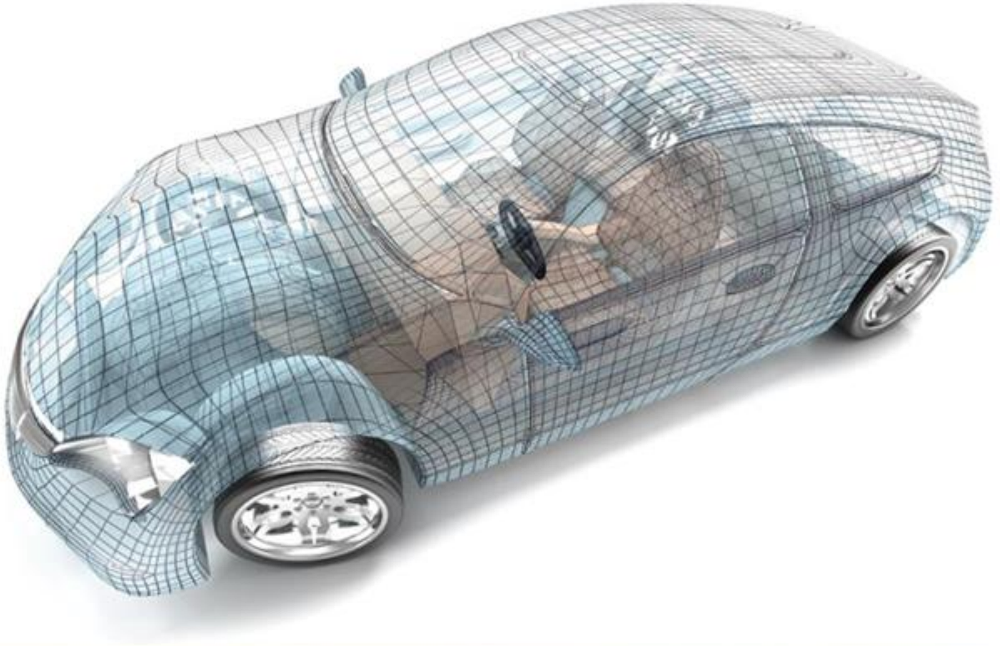
THERMOPLASTIC COMPOSITES CONFERENCE
TCC 2020

A VIRTUAL EVENT
APRIL 29 – MAY 1, 2020



Novel Welding Method for Thermoplastic Fuselage Structures

Presented By: Mark Wadsworth
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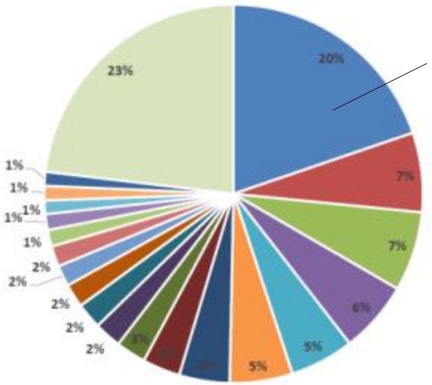
Spirit AeroSystems Inc.

Intro to Spirit AeroSystems

>15,000 employees

Global aerostructures leader



SPIRIT AEROSYSTEMS

Source: Counterpoint

Balanced aerostructures portfolio

Fuselage
(52%)

Propulsion
(26%)

Wing
(22%)

Emerging presence in Defense

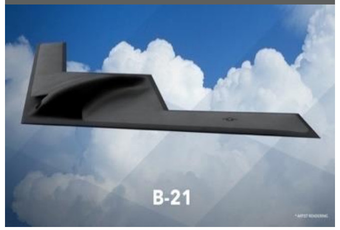
Sikorsky CH-53K

Bell V-280

P-8A, P-8I

KC-46A Tanker

Northrop Grumman B-21



On all of 12,600 Boeing/Airbus backlog

Spirit is the Leading Global Tier 1 Aerostructures Supplier

Thermoplastic Welding Development Approach

Autoclave fusion
Induction
Conduction
Ultrasonic
AFP Welding
Friction
Induction

Basic Research and Evaluation

TRL 3

weaknesses
limitations
bottlenecks

Development and Testing

TRL 4

Characterization and Demo articles

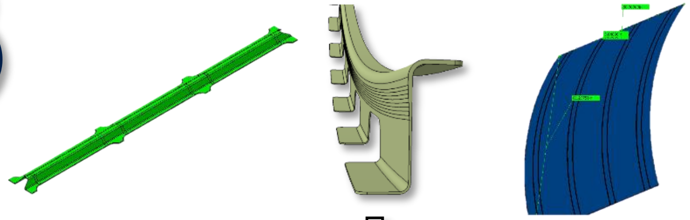
TRL 5

Innovate

Appreciate

Evaluate

Configuration & Engineering



Known welding methods, scholarly research, industry trends, etc.

Understand joint features and requirements

Compare productivity, costs (capitol, labor, energy, expendables), limitations etc.

Procure/fab equipment & materials; Weld coupons

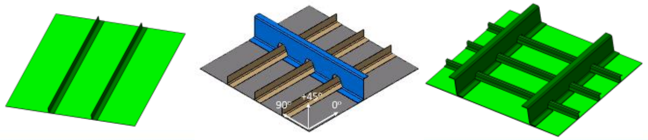
Compare reliability, sensitivity, inspectability, compatibility, etc.

Evaluate welding methods, match to applications

Compare porosity, mechanical strength, crystallinity, etc.

Down-select technologies

Deliver demo article, screening data, prototype equip.

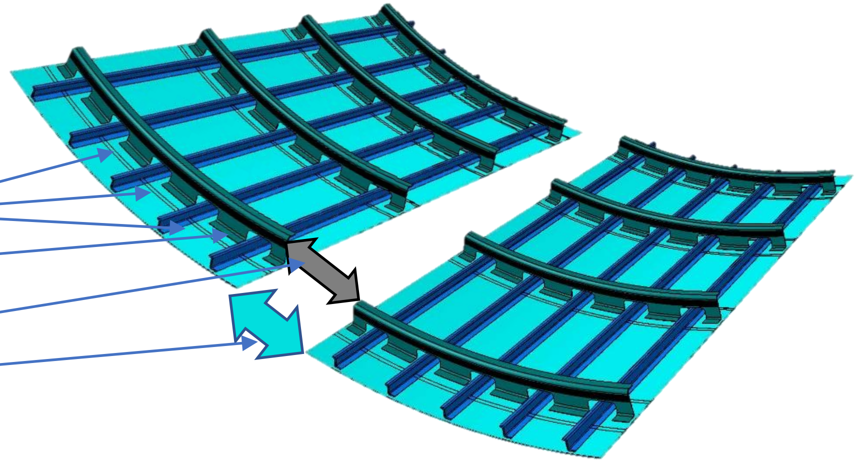


Thermoplastic Welding Process Comparison

Joining Method	Heat Type	Weld Area Control Method	Tooling Requirement	Feedback for Control or Validation
Conduction	Heated platen	Platen/heat sink area	Heated platen, cauls, heat sinks	Direct surface temperature
Induction	Induction of eddy currents	Coil, laminate and heat sink properties	Back-side support and pressure applicator, non-ferrous material	Indirect temp or via invasive sensor, process control
Resistance	Metal resistor in joint	Resistor area, current distribution, heat sink	Heat sinks, pressure applicator, back side support	Indirect temp or invasive sensor, process control
Co-Fusion	Heated tool	100% of faying surfaces	Heated OML tooling	Thermocouples on back of welding flange
In-Situ AFP	Laser, IR	Tooled stiffener position	IML tool with stiffener backup support	In process pyrometer feedback,
Autoclave Fusion	Autoclave gas	100% melt, inside and outside weld	Tool or bag 100%	Thermocouple in tool, driven by lagging

Thermoplastic Welding Process Applications

Joints
- Stringer/Skin
- Frame/Skin
- Frame/Frame
- Skin/Skin



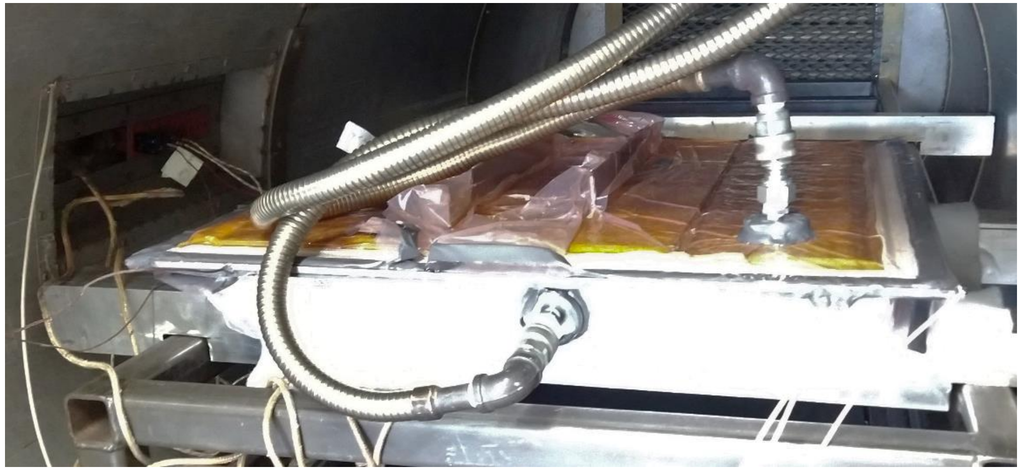
Joining Method	Incompatible	Cost	Rate	Performance	Application
Conduction		Some tooling	Slow		All
Induction		Some tooling	Slow	Risk	All
Resistance		Some tooling	Slow	Concern	Frame/Frame
Co-Fusion	Frame/Frame				Stringer/Skin, Frame/Skin
In-Situ AFP	Frame/Frame	High tooling, performance risk		Risk	Stringer/Skin, Skin/Frame
Autoclave Fusion	Skin/Skin	High tooling, capital, expendables			Tooling scale, cost, cost, cost

Cost addresses labor (fab and assembly, material, consumables)

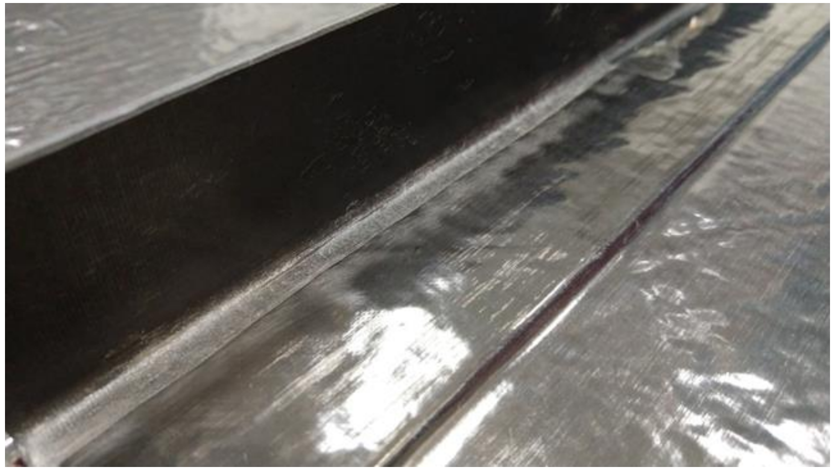
Co-Fusion Process Description

Novel Conductive Thermoplastic Welding Method

- Spirit Co-Fusion is a patent pending joining method
- Re-melt the skin while welding stiffeners
  - Thermal gradient is created through the joint
  - Relieve stress induced warpage from AFP
  - Completes consolidation after AFP
- Reduces costs
  - One OML tool from AFP through assembly
  - Enables compliance for assembly tolerance relief
  - Low temperature autoclave provides economical/available pressure
  - No need for high temperature bagging materials
  - Vacuum bag only (VBO) in some cases



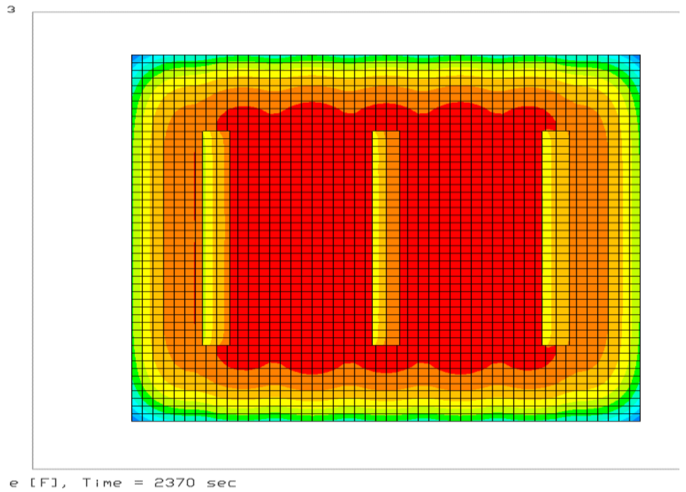
Co-Fusion in room temperature autoclave

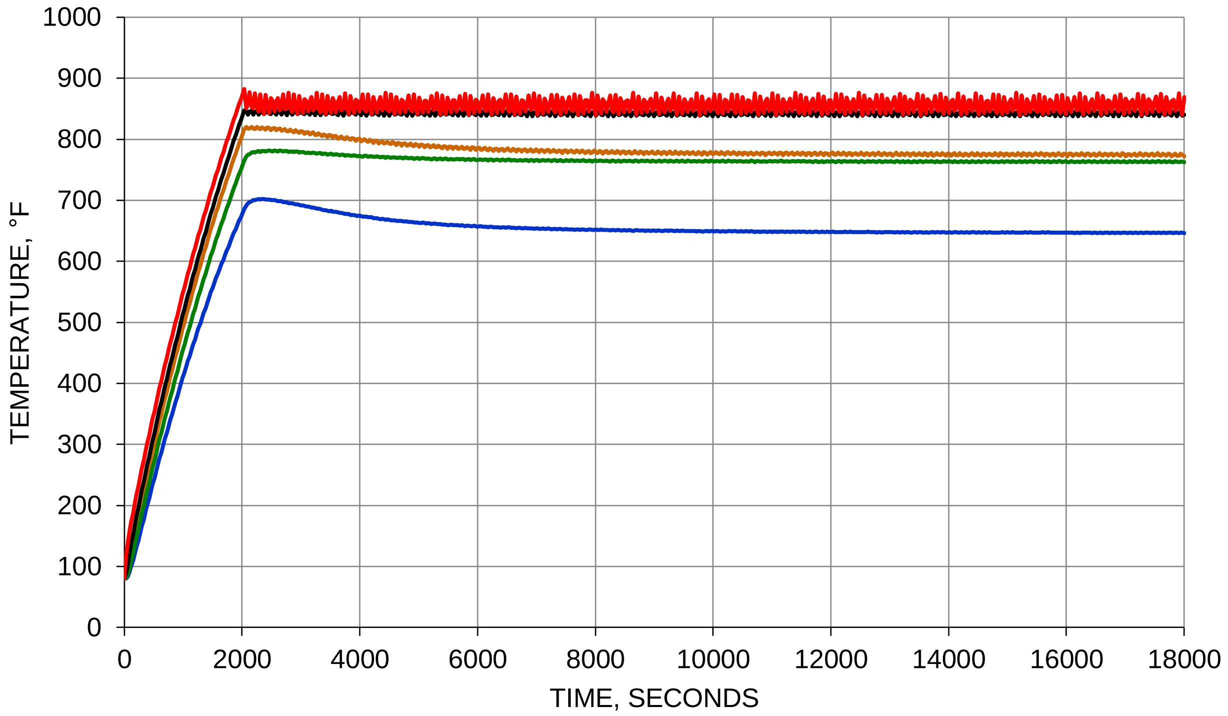


Co-Fusion stiffener joint after VBO process

Thermal Modeling of Co-Fusion

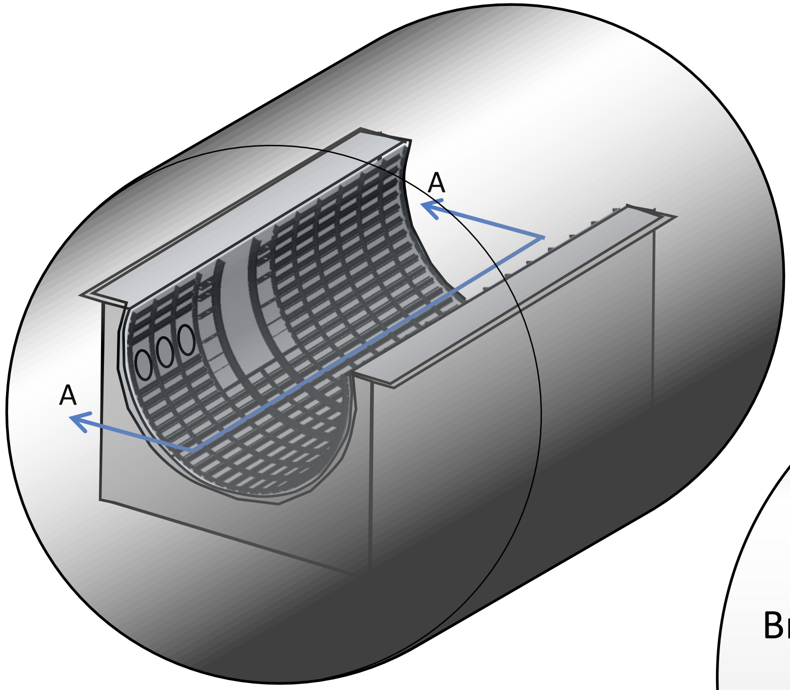
- Thermal models useful for initial insulation and power density sizing
- Boundary conditions such as convection coefficients can be difficult to predict, can be tuned empirically.
- Some thermal properties change during the process due to consolidation and absolute pressure changes.



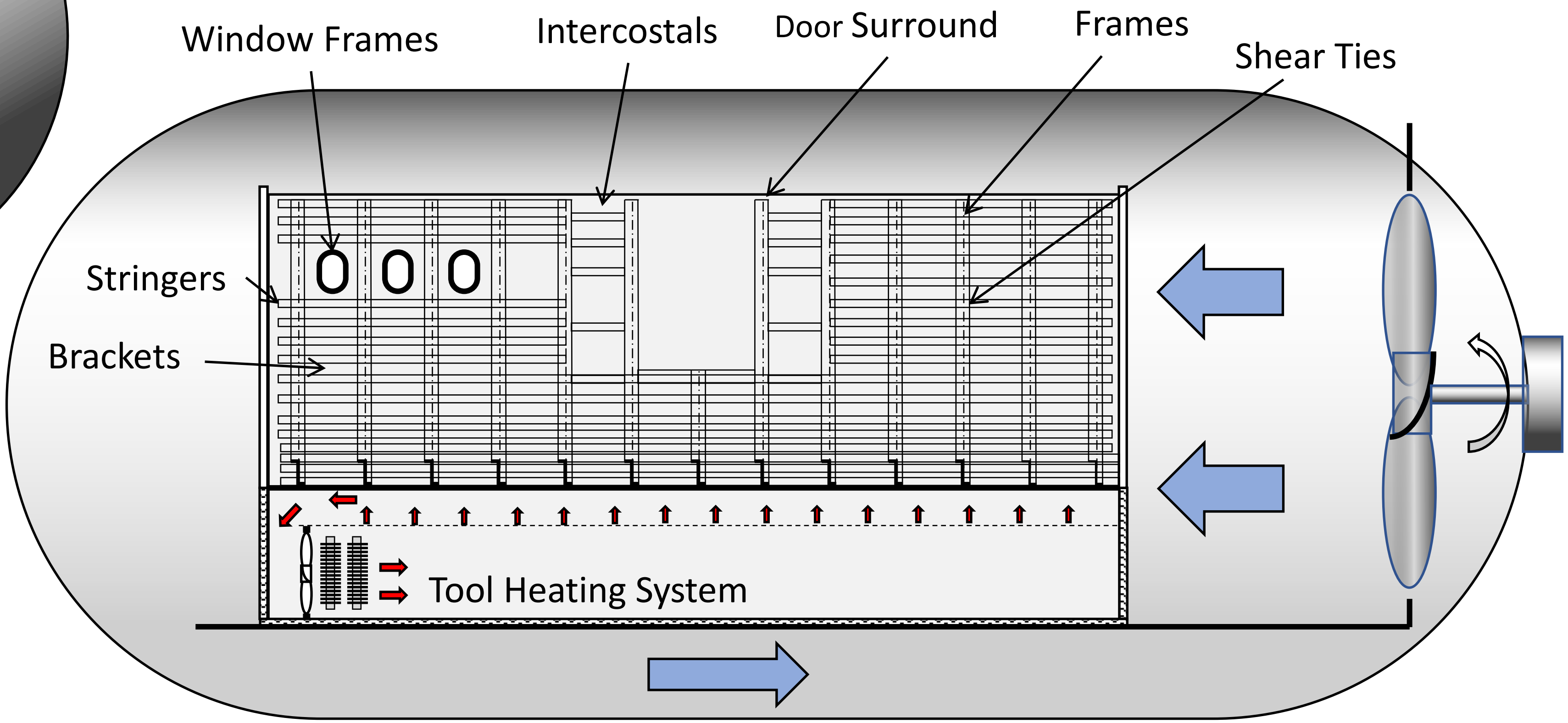


Large Scale Application of Co-Fusion

Potentially many types of substructure can be welded simultaneously



Unheated Pressure Vessel or Standard Autoclave without heat



Section AA

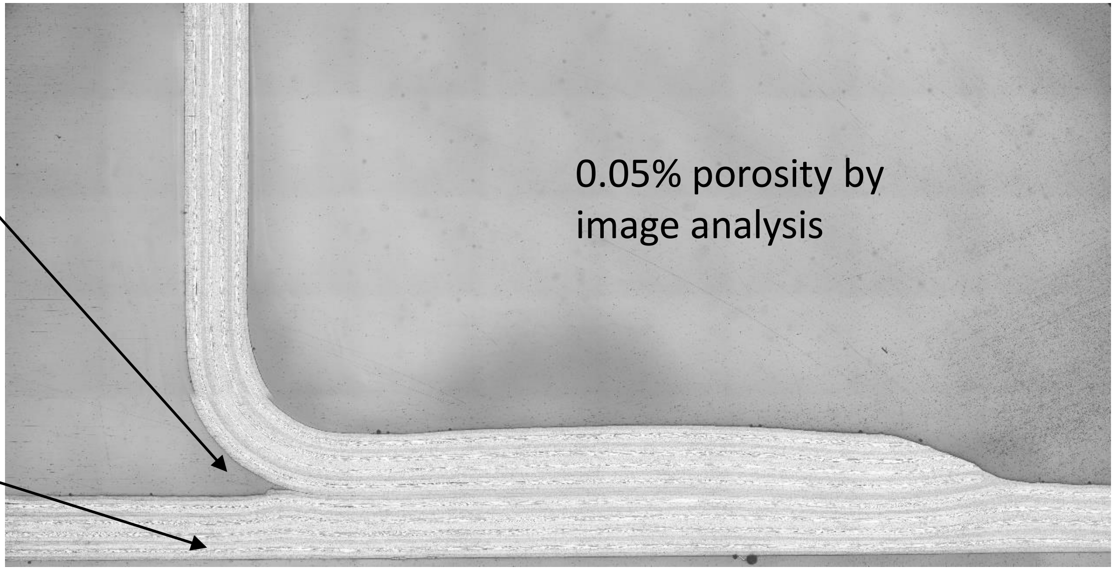
Characteristics of Co-Fusion Welds

No mark-off of stiffeners or welds on tool surface

With or without radii filler

Skin can be pre-consolidated or consolidated during welding

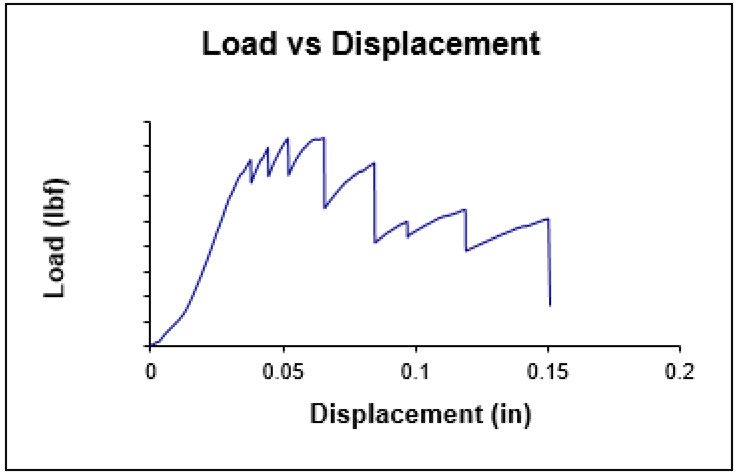
Laminate and angle stiffeners Co-fused at 100 PSI in 1 hour



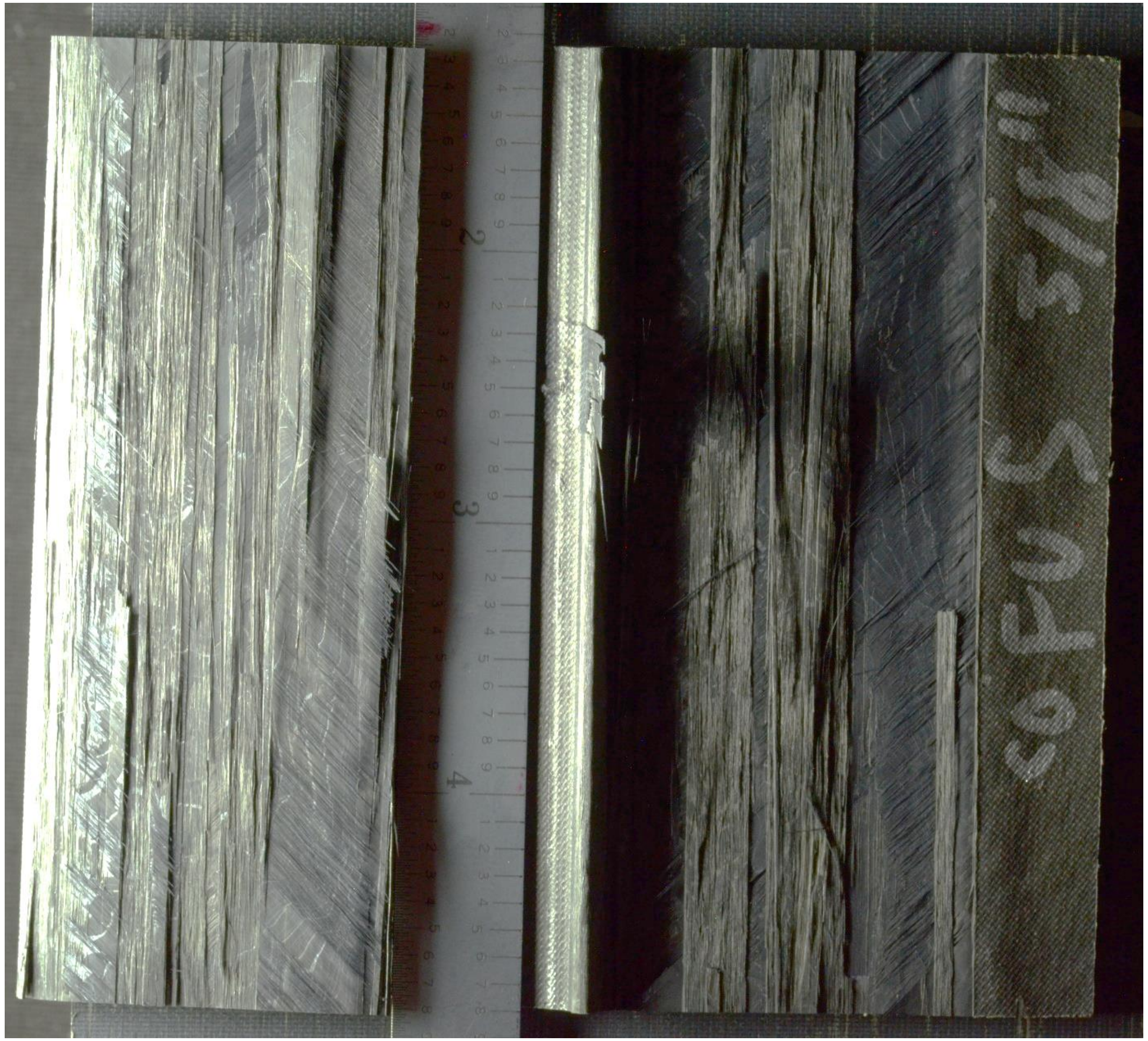
0.05% porosity by image analysis

Properties of Co-Fusion Welds

Mechanical Pull-off Test



Welds absorb substantial energy before failure



Fracture surface after pull-off, 100% of surface is welded

Summary

- Spirit is patenting a novel thermoplastic welding process
  - The process welds structure anywhere on the back of the skin at the same time that the skin is fully consolidated
  - Warpage stresses from AFP are relieved
  - The skin is annealed for full crystallinity
  - No tooling is required on most of stiffener elements
  - High temperature bagging materials are avoided
  - Ordinary thermosetting autoclave or unfired pressure vessels can be used
  - Welds exhibit good strength and can be validated in-process

Thank You!