Boeing Research & Technology

Dreaming
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Development of a Bismaleimide (BMI) Repair Capability

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Producing
Leading
Creating
Researching
Analyzing

Agenda

- Introduction / Background
- High Temperature Wet Layup Repair
- DVD Development for F650 Fabric
- DVD Development for 5250-4 Fabric
- BMI Adhesive Evaluation and Bonding Process Development
- Conclusions & Future Work

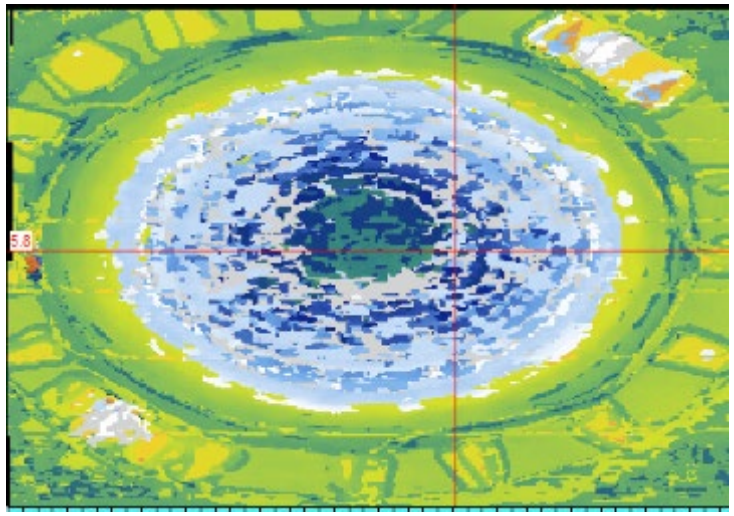
Overview

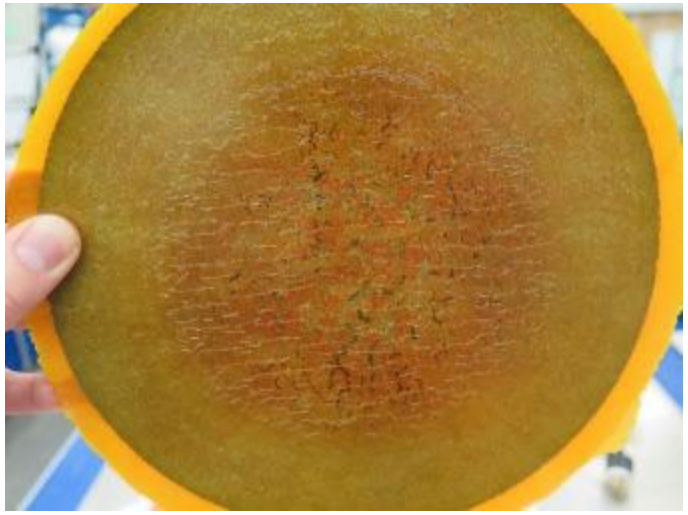
BMI parts are used on multiple platforms:

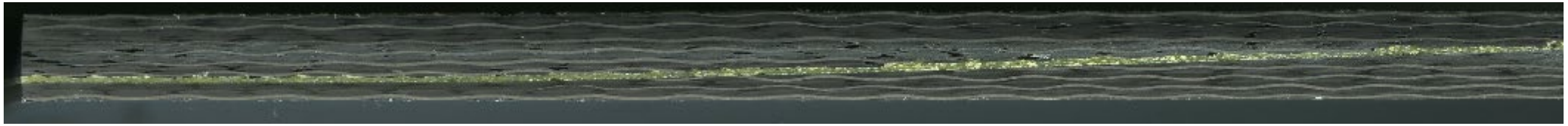
Increasing use with high temp requirements

Challenges in Bonded Repair to BMI Structures

- Low resin content requires no-to-minimal bleed
- Low viscosity requires resin containment or rheological “adjustments”
- Volatiles released result in high void content OOA
- High temperature cure requirements (440°F post-cure)



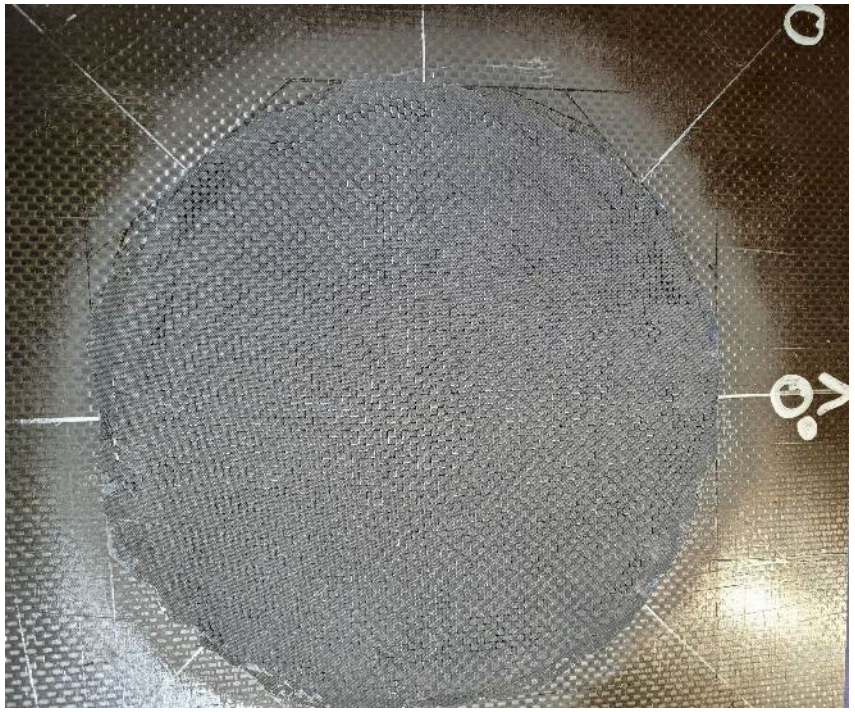




Typical result is a porous & sometimes resin starved repair

High Temperature Wet Layup Repair

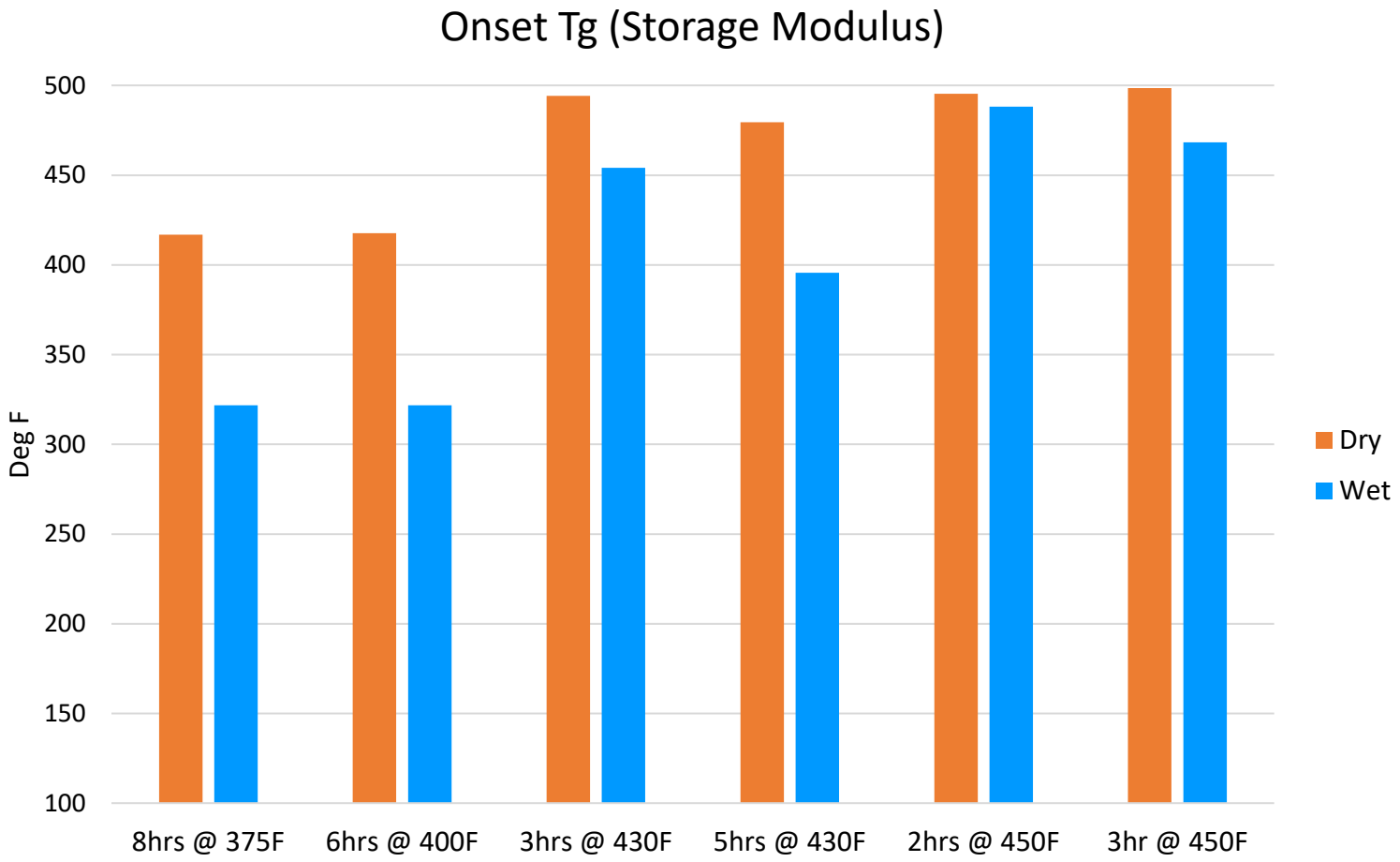
- **Utilizes Henkel's RI 9502 high temperature epoxy resin and a Horizontal Squeeze-Out process similar to ARP5319 Section 8.1**
- **Advantages of a wet layup repair:**
  - Materials are room temperature storable
  - Doesn't require bulky equipment like a DVD chamber
  - Fast processing time
- **Proof of Concept Testing Performed:**
  - DMA Tg testing for different cure profiles
  - Scarf repair and panel process testing with quality/porosity assessments
  - Mechanical testing: UNC, SBS, and DCB



High Temperature Wet Layup Repair

DMA Tg Testing:

Panel #	Initial Dwell	Post Cure
1	8hr @ 375F	none
2	6hr @ 400F	none
3	1hr @ 355F	3hrs @ 430F
4	1hr @ 355F	5hrs @ 430F
5	1hr @ 355F	2hrs @ 450F
6	1hr @ 355F	3hrs @ 450F

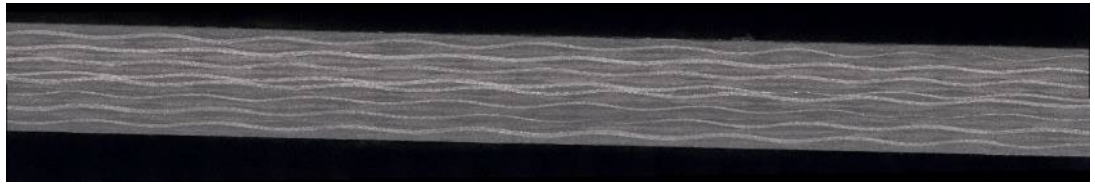


* Wet samples were soaked in a 160F water bath for 2 weeks

High Temperature Wet Layup Repair

Process Testing:

Testing Performed in 2020

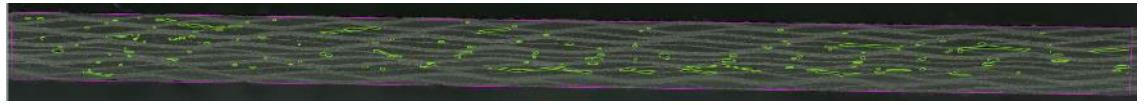


16 ply panel

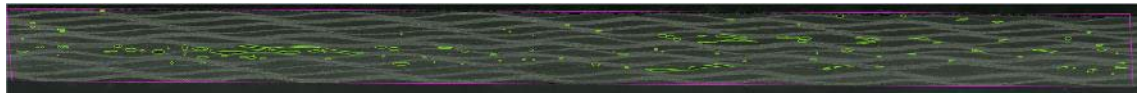
8 ply panels

Current Testing

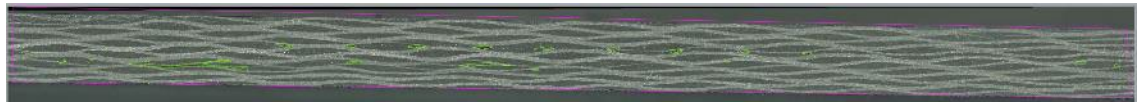
12 ply panels



2.63% porosity

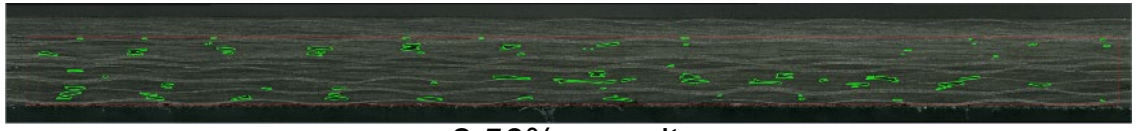


1.84% porosity

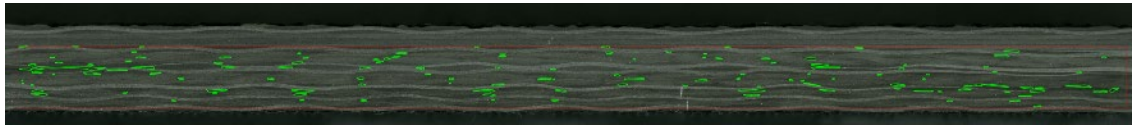


0.56% porosity

12 ply scarf repairs



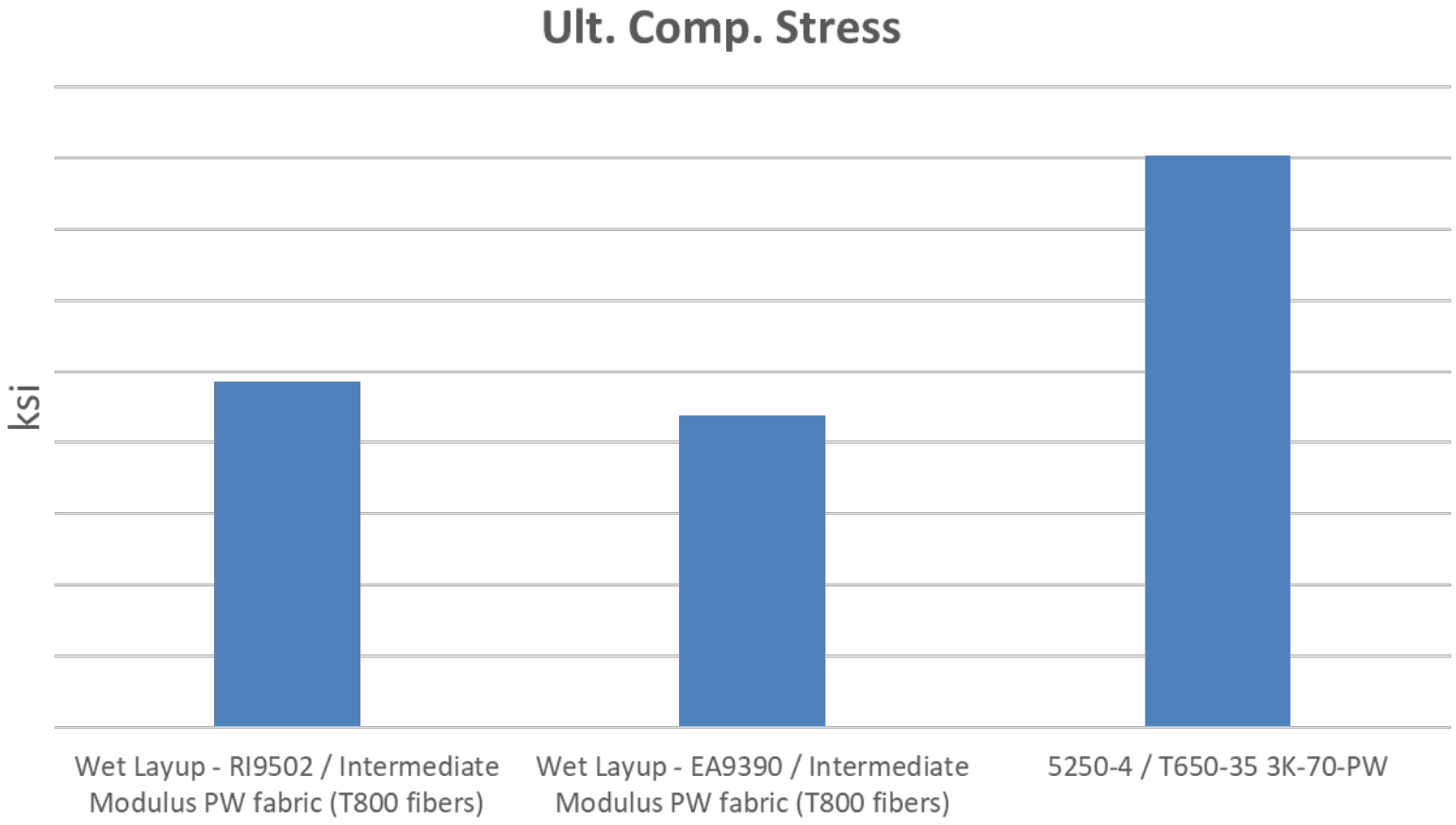
2.56% porosity



1.94% porosity

High Temperature Wet Layup Repair

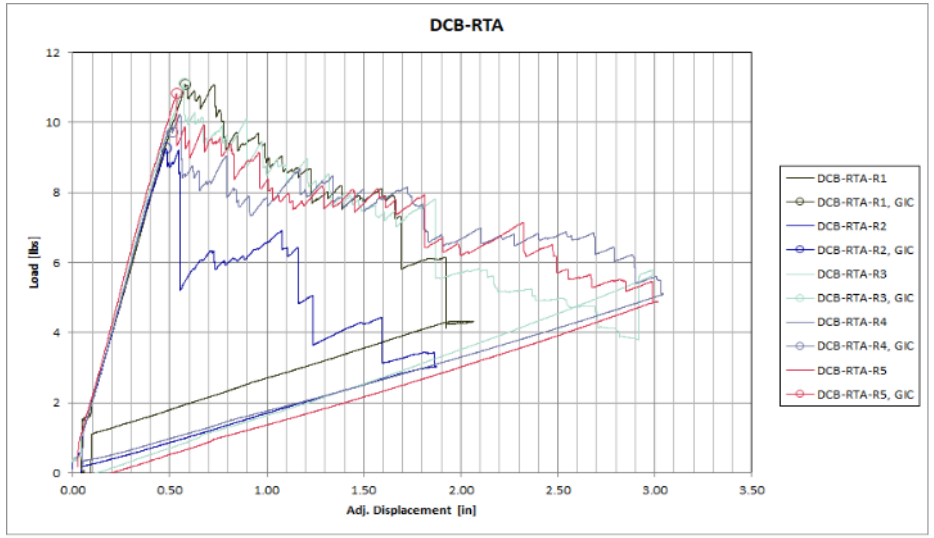
Mechanical Testing – RTA Unnotched Compression Results:

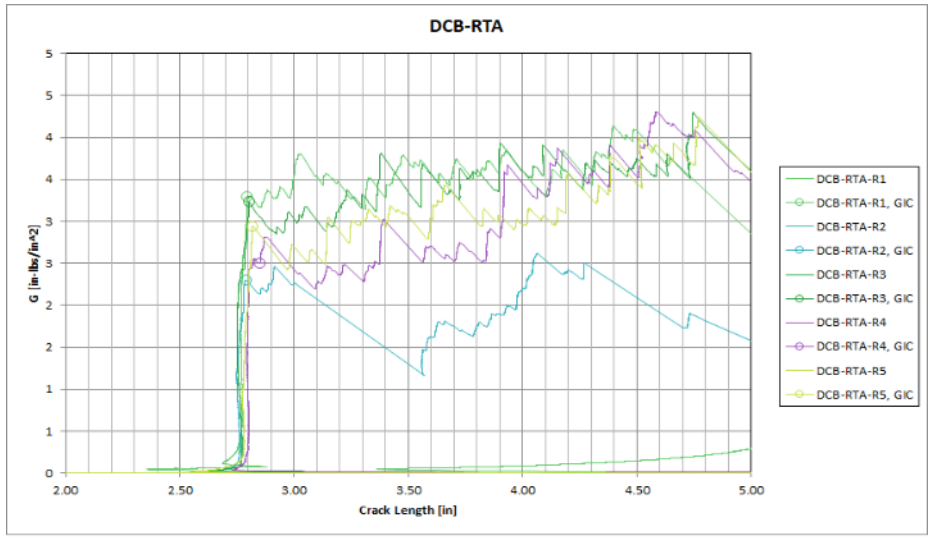


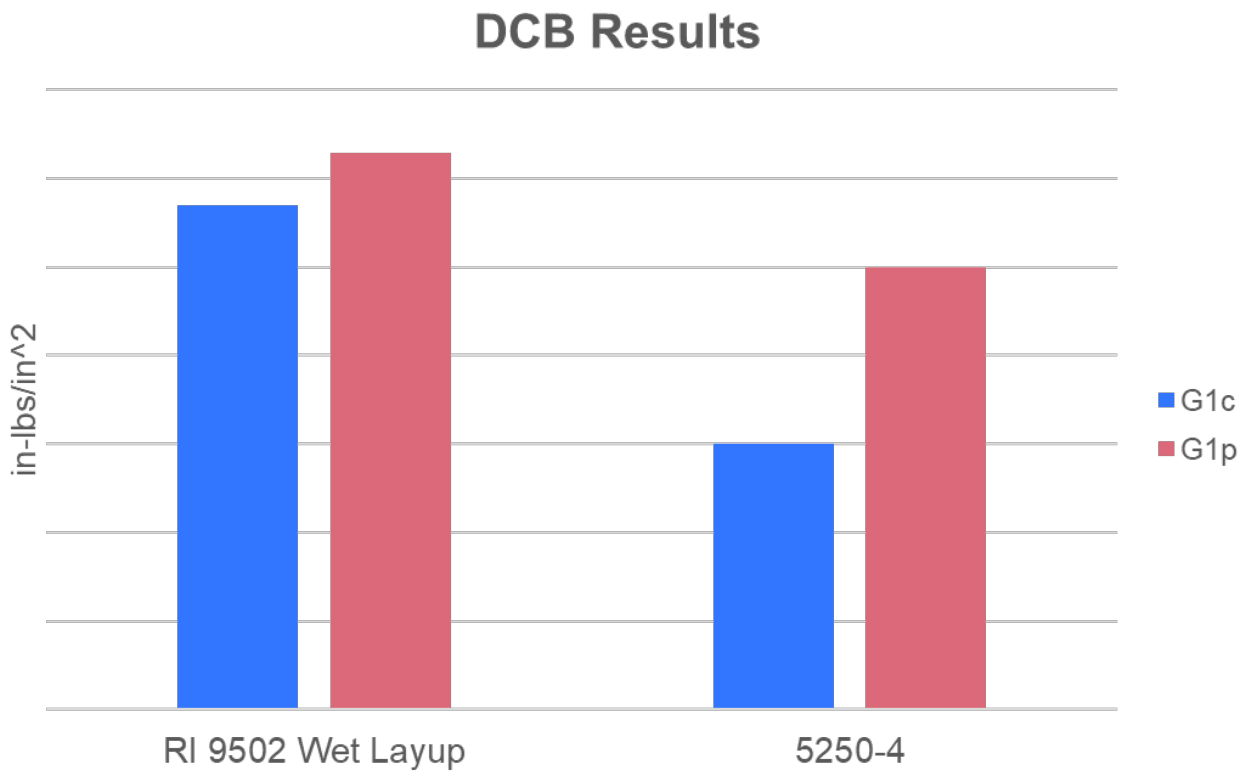
Note: all results from 16 ply thick, quasi-isotropic layups

High Temperature Wet Layup Repair

Mechanical Testing – RTA Double Cantilever Beam Results:



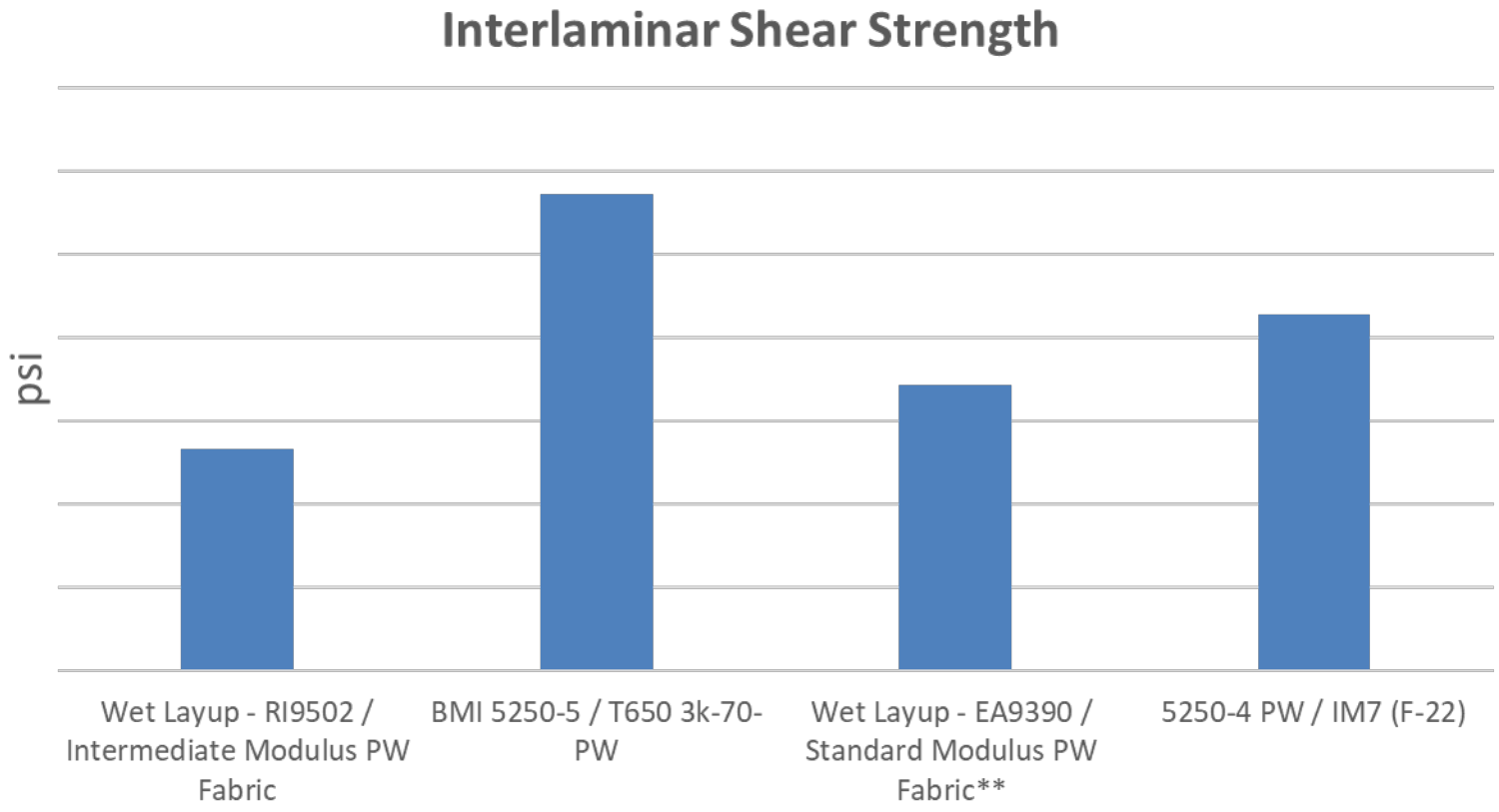




Sufficient bond strength that an additional paste / film adhesive is not needed

High Temperature Wet Layup Repair

Mechanical Testing – RTA Short Beam Shear Results:



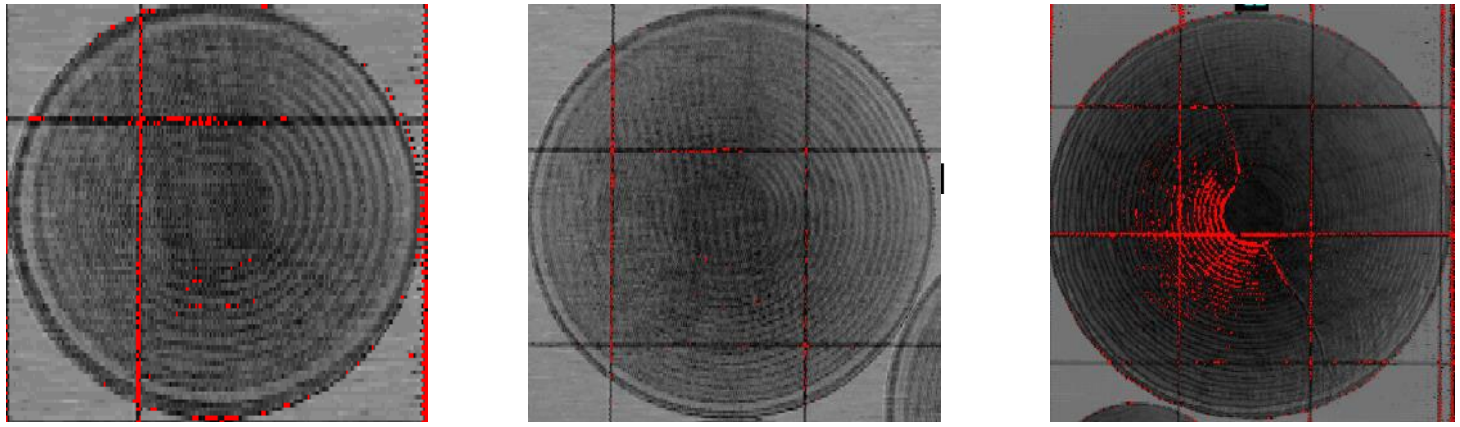
**From specimens where wet layup is bonded to CFRP prepreg

F650 Fabric DVD Cycle Development

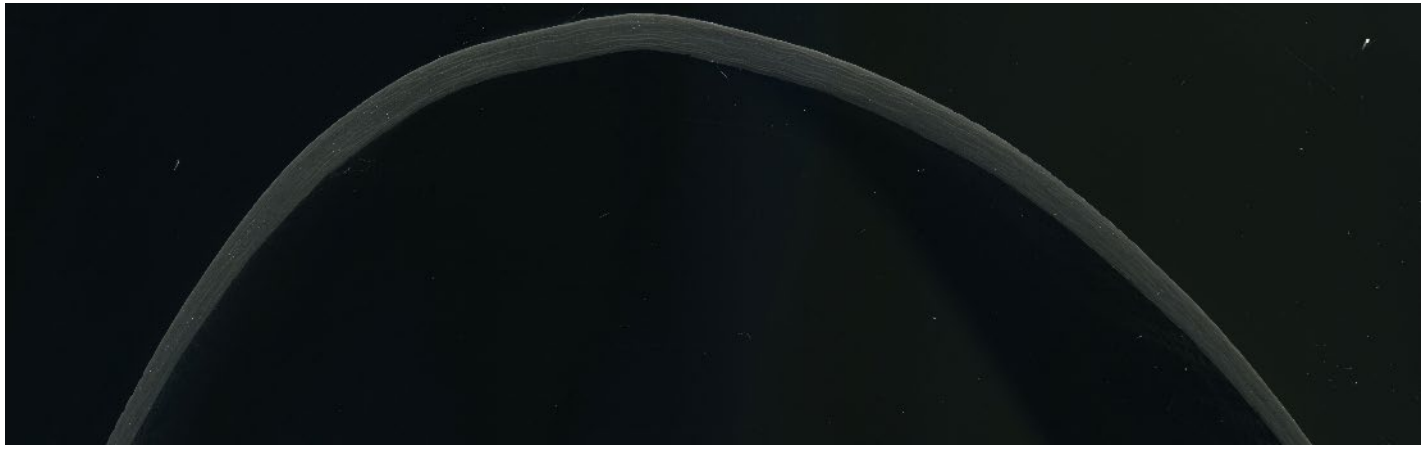
Performed process testing to determine a DVD cycle that will result in low porosity consolidated patches

- Utilized DVD bagging aimed at limiting resin loss
- F650 proved to be robust with multiple DVD temperatures working

12 ply patch **20 ply patch** **32 ply patch**



2% porosity in red (everything else < 2%)

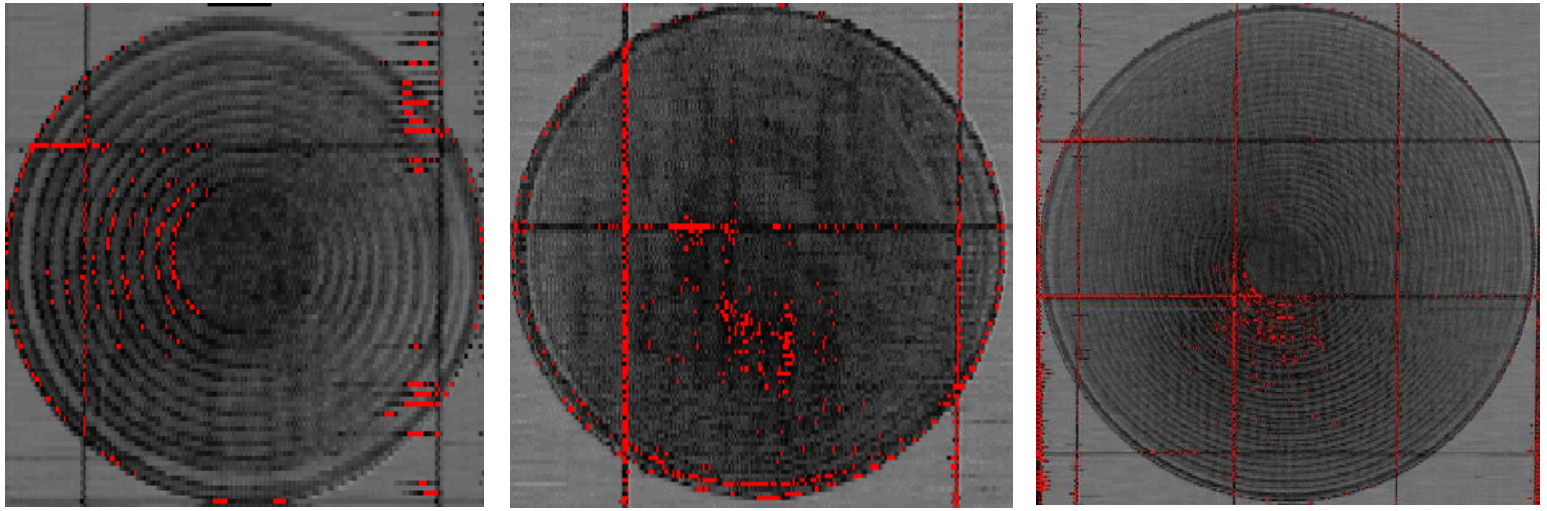


5250-4 Fabric DVD Cycle Development

Performed process testing to determine a DVD cycle that will result in low porosity consolidated patches

- Utilized DVD bagging aimed at limiting resin loss
- 5250-4 processes a little less consistently so far, but high quality patches were still achieved

12 ply patch **20 ply patch** **32 ply patch**



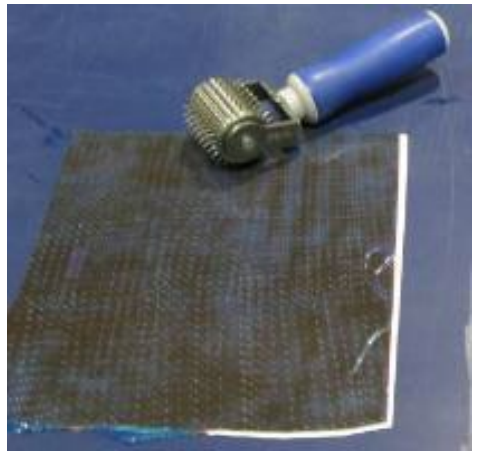
2% porosity in red (everything else < 2%)

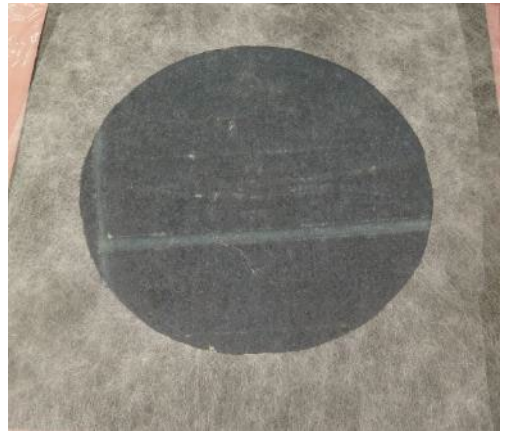
Bonding Process Development

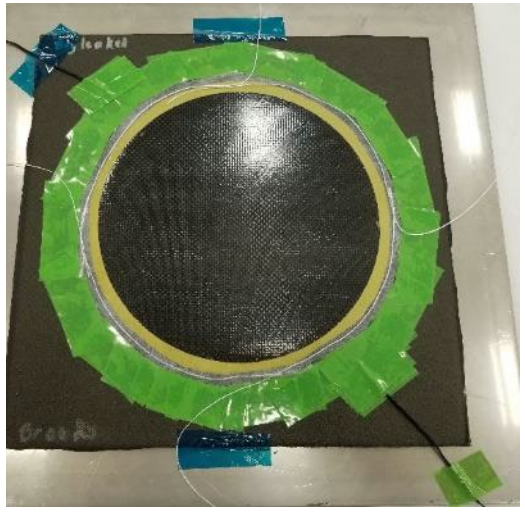
Scarf repair trials were done using different combinations of adhesives and processing techniques to evaluate resulting repair quality. Variables included:

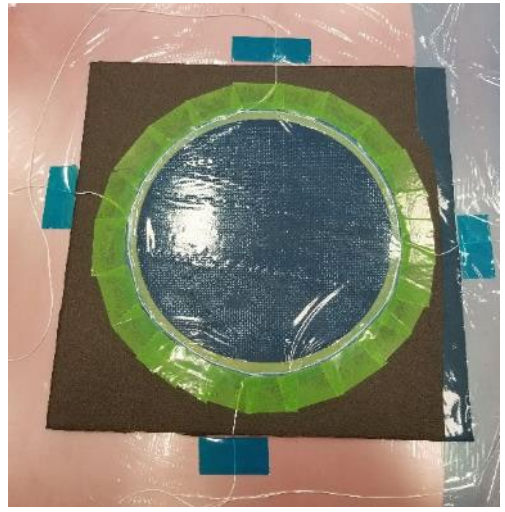
- **Adhesives:**
  EA 9673, FM 450-1, MB 2550G, RM-3011
- **Breathing Techniques:**
  Perforating adhesive, perforated/porous separators, breather strings, adding 1 or 2 layers scrim, bleeder materials
- **Consolidation Techniques:**
  Edge dams, regulated vacuum, room temp compaction prior to cure
- **Cure Techniques:**
  Slower ramps, intermediate dwells
- **Material Techniques:**
  Drying, staging

**All patches are 5250-4 or F650 fabric that have been processed using DVD prior to bonding



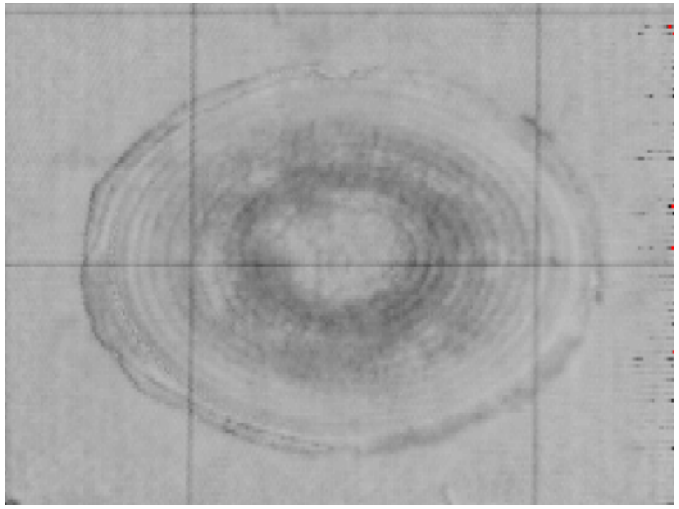






Bonding Process Development

Adhesive	Bagging / Processing Details	Cure
MB2550G (0.06 psf, 10 mils thick)	Utilized a bagging scheme aimed at limiting bleed and resin loss through the top of the repair while still breathing the bondline using edge breathing techniques	Intermediate hold & slow ramp to limit flow

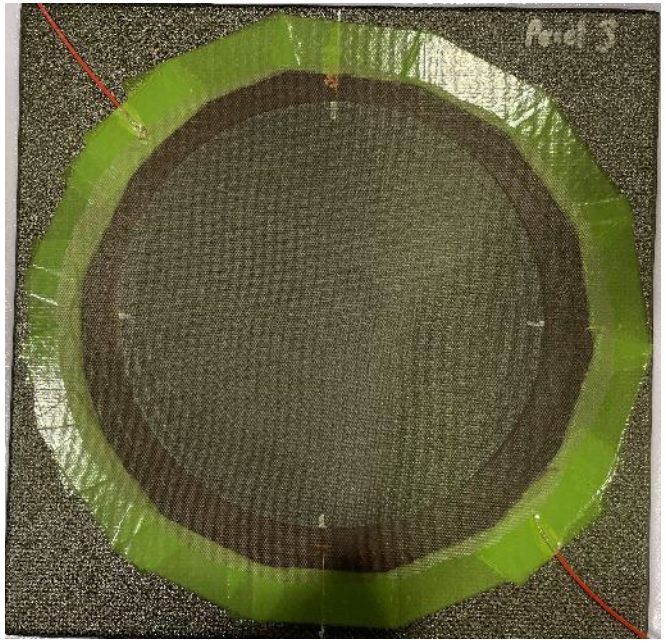


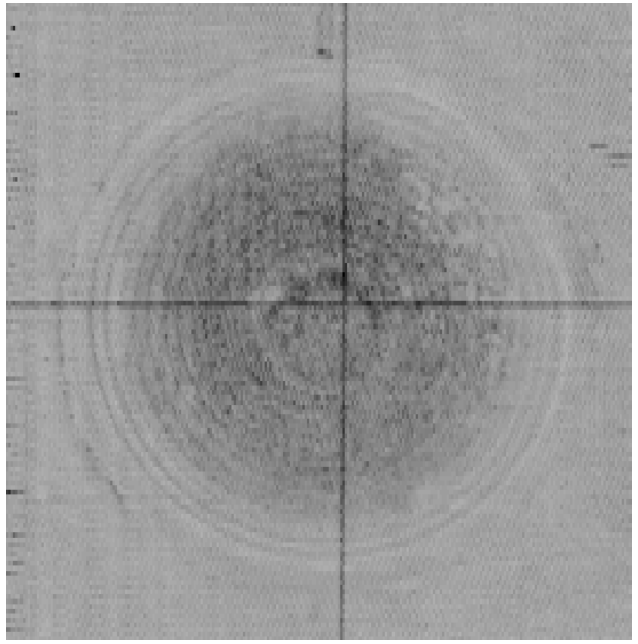
Amplitude

Poor Quality

Bonding Process Development

Adhesive	Bagging / Processing Details	Cure
RM-3011 (0.06 psf, 9-10 mils thick)	Utilized a bagging scheme aimed at limiting bleed and resin loss through the top of the repair while still breathing the bondline using edge breathing techniques	Intermediate hold & slow ramp to limit flow



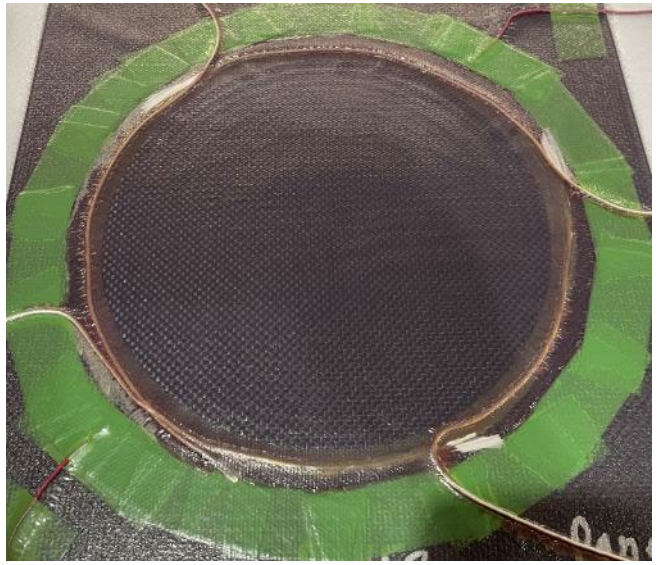


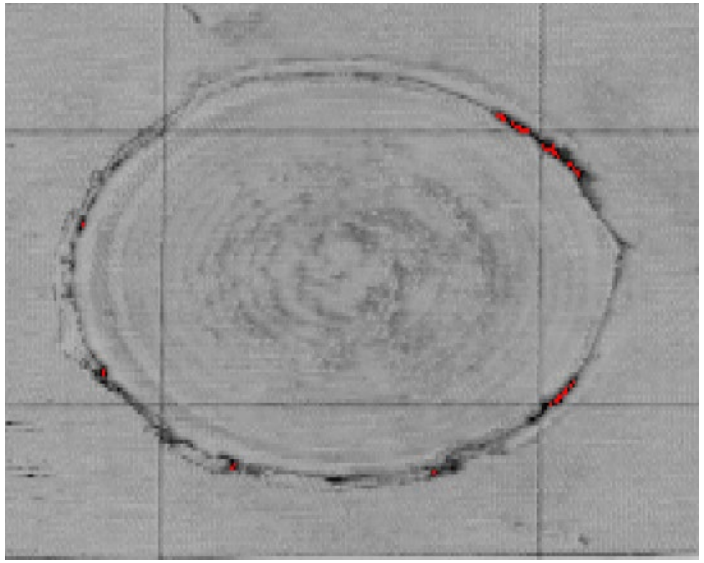
Amplitude

Poor Quality

Bonding Process Development

Adhesive	Bagging / Processing Details	Cure
FM 450-1 (0.06 psf, 6 mils thick)	Utilized a bagging scheme aimed at limiting bleed and resin loss through the top of the repair while still breathing the bondline using edge breathing techniques	Intermediate hold & slow ramp to limit flow



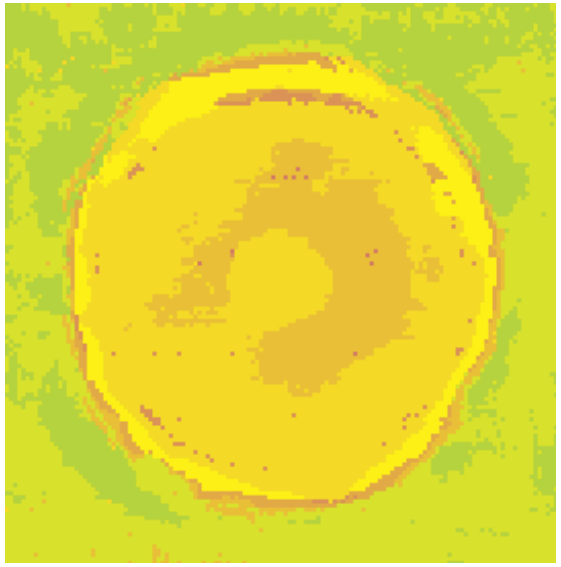


Amplitude

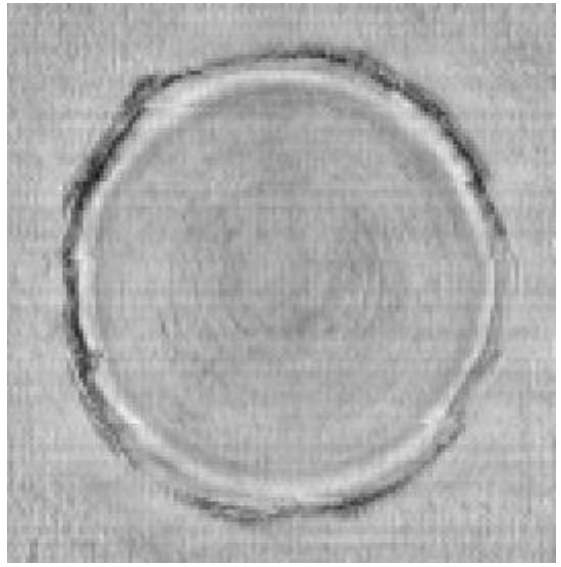
Acceptable Quality

Bonding Process Development

Adhesive	Bagging / Processing Details	Cure
EA9673 (0.1 psf, 15 mils thick)	Utilized a bagging scheme aimed at limiting bleed and resin loss through the top of the repair while still breathing the bondline using edge breathing techniques	Intermediate hold to limit flow



Time of Flight



Amplitude

Good Quality

Conclusions

- High temperature wet layup repair using RI 9502 resin demonstrated to be viable structurally and meets BMI temperature requirements.
- High quality patches were produced using DVD for 5250-4 & F650 fabric
- High quality bonding process demonstrated:
  - Of the BMI adhesive options EA9673 was found to be the clear highest performer
  - FM450-1 performed satisfactorily but in a clear 2nd
  - Bagging and cure profiles focusing on reducing flow and bleed were found to work best

Future Work

Planned:

- Validate moisture removal cycle
- Full design values testing for repairs using F650 and 5250-4 with EA9673 adhesive
- Large panel testing
- NDI procedure development

Targeted:

- Develop 5250-4 tape repair
- Finish development of high temperature wet layup repair

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