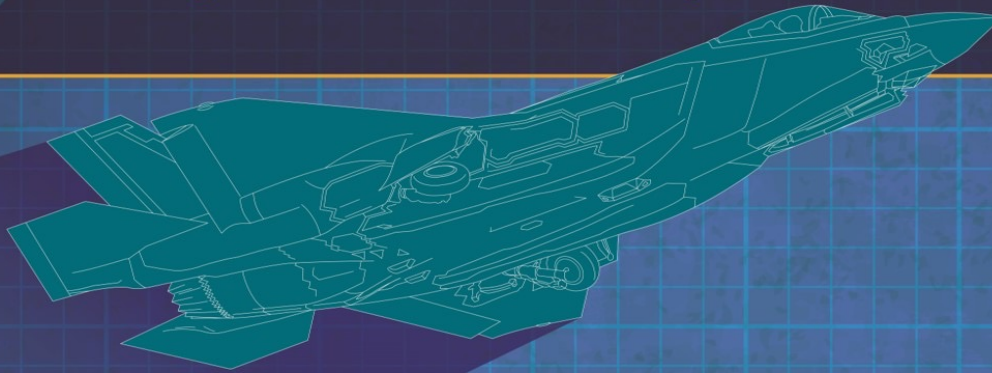


PART WORKS

Reinventing The Future Of Cold Expansion™

COLLABORATE WITH US
FOR EARLY ACCESS TO OUR
PATENT-PENDING* WORK



Authors:

Jude Restis

Doug Glenn

Dr. Matthew Kokaly

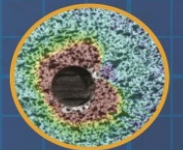
Dale Manning

Bolt Hole Corrosion and Fatigue Damage Repair
in Hybrid Structure

Presented by Jude Restis & Dr. Matt Kokaly

Dec 2022

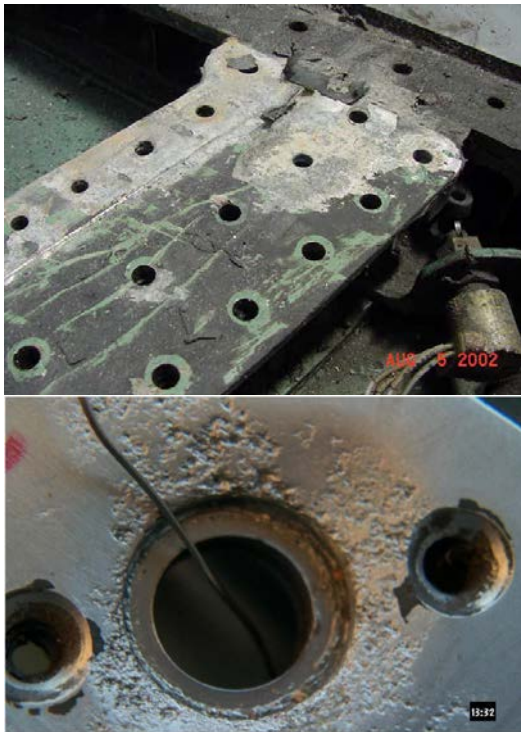
PARTWORKS.COM



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Galvanic Corrosion of Hybrid Structure

Widespread galvanic corrosion damage experienced on multiple programs with composite over aluminum in the presence of moisture



Navy IG Report
As reported in Navy Times
By Diana Stancy Correll
Oct. 5, 2021

“Between FY17 and FY20, corrosion costs accounted for \$2,086,796,553, amounting to 29.4 percent of the total maintenance cost for [F-18C-G] aircraft.”

From “In-service Corrosion Issues in Sustainment of Navy Aircraft” briefing, R. Mendoza, Aug 2012

F-18: Canary in the Coal Mine

F-18's Awaiting Depot Induction at North Island

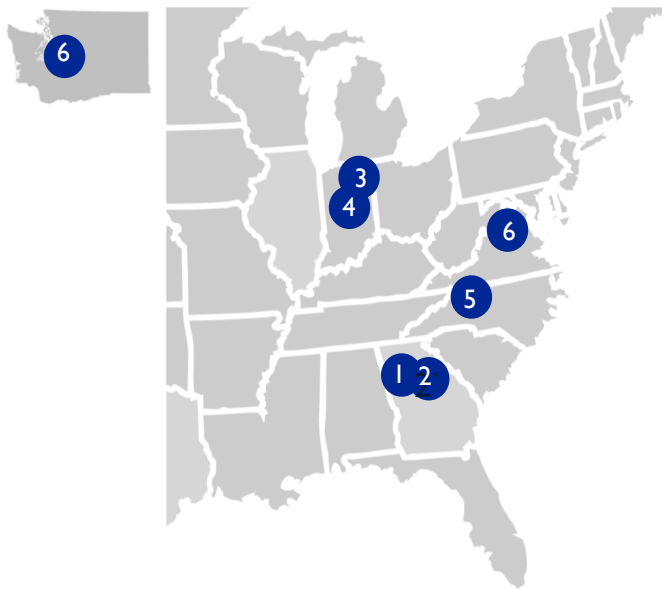


Navy indicated to repair a single corroded bolt hole may take several weeks and cost many thousands of dollars

Leveraging years of experience and extensive knowledge of airframe design and repair, Mike Dubberly & Partworks conceived of better way to repair corroded fastener holes

The PartWorks ultra-thin wall rivetless nutplate repair process was developed

Corporate Overview



PART WORKS

**IS A WHOLLY OWNED
SUB OF**

PHX HOLDINGS

- | | |
|---|--|
| 1 PHX Holdings
Atlanta, Georgia | 4 GTC Machining
Indianapolis, Indiana |
| 2 PartWorks
PSG* Plants 1 & 2
Atlanta, Georgia | 5 PSG* Plant 4 NC
Charlotte, NC |
| 3 PSG* Plant 3 Indiana
Fort Wayne, Indiana | 6 PartWorks
Field Offices
Alexandria, VA
Seattle, WA |

Combined annual revenue > \$100M
>250+ employees, 375,000+ sq. feet
GTC is AS9100D, ITAR

*PSG=Phoenix Stamping Group: ISO 9001-2015

USAF Test Program

Carried out in Conjunction with:

University of Dayton Research Institute (UDRI)

Goose Meadow Engineering at Montana State University

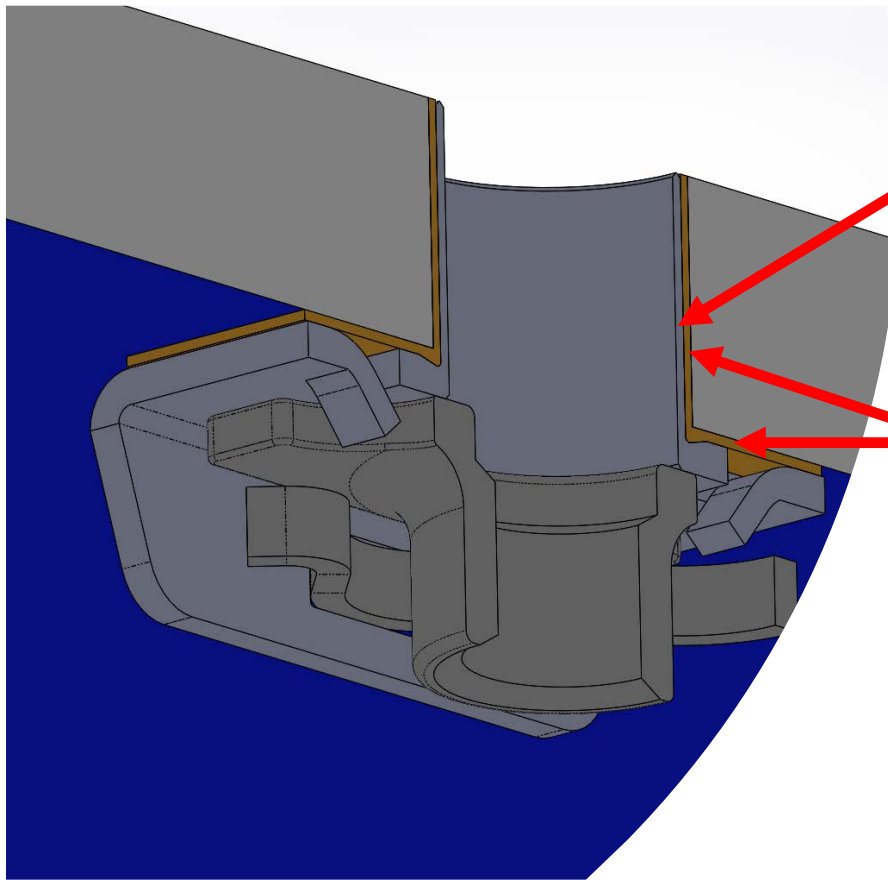
Georgia Tech

- Quantify damage experienced on USAF Fleet due to galvanic corrosion
- Develop techniques to replicate corrosion damage on test coupons
- Perform fatigue testing to assess debit/enhancement in fatigue life due to corrosion and Partworks repair
- Perform computational analysis to correlate fatigue behavior and predict residual stress
- Evaluate residual stress field using Digital Image Correlation (DIC) and correlate with X-Ray diffraction measurements and FEA
- Develop tooling and measurement techniques to allow taking credit for repair (in-process measurements)
- Develop Adhesive & Sealant to prevent corrosion

Project Goals

- Simplified / Standardized Repair
- Preserve edge margin
- Provide fatigue life benefit
- Protect against undetected or missed damage
- Reduce analysis time
- Increase fleet readiness
- Allow credit for engineering residual stress
- Save cost

PartWorks Repair - Rivetless Nut Plate



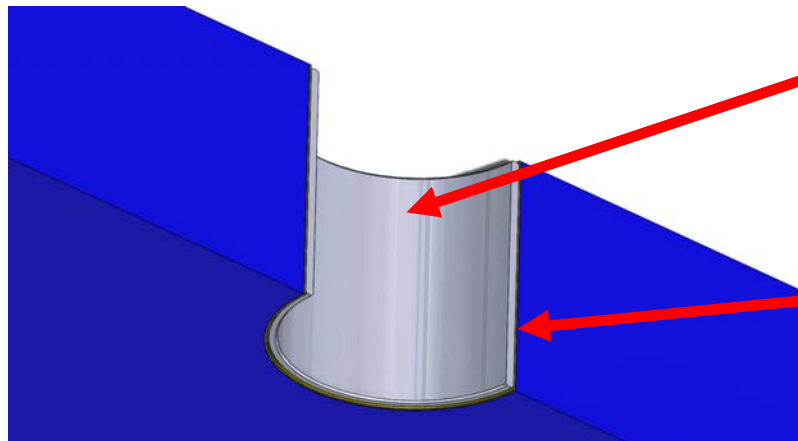
Thin wall

- **CRES Retainer barrel**
- **Minimizes material removal**
- **Maximizes e/D**
- **Maximizes cold expansion to the structure**

Adhesive

- **Maximizes torque-out and push out**
- **Galvanic barrier**
- **Minimal surface preparation**

PartWorks Bushing Repair



Thin wall

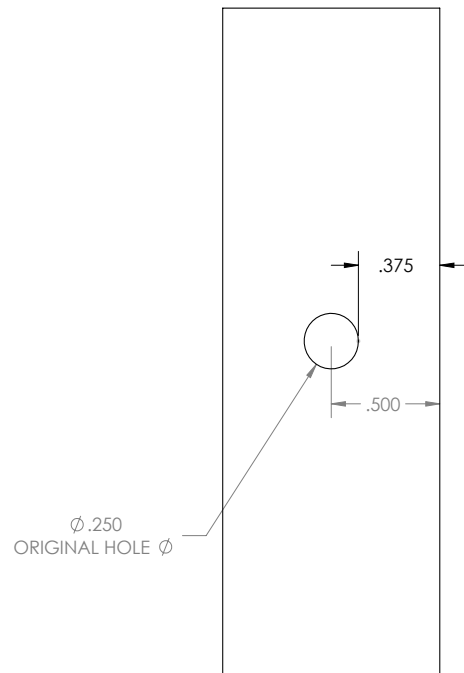
- **CRES Bushing barrel**
- **Minimizes material removal**
- **Maximizes e/D**
- **Maximizes cold expansion to the structure**

Adhesive

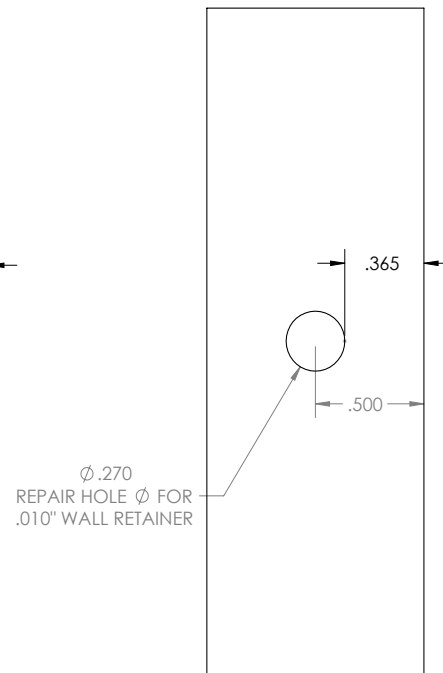
- **Galvanic barrier**
- **Minimal surface preparation**

Preserve Edge Margin

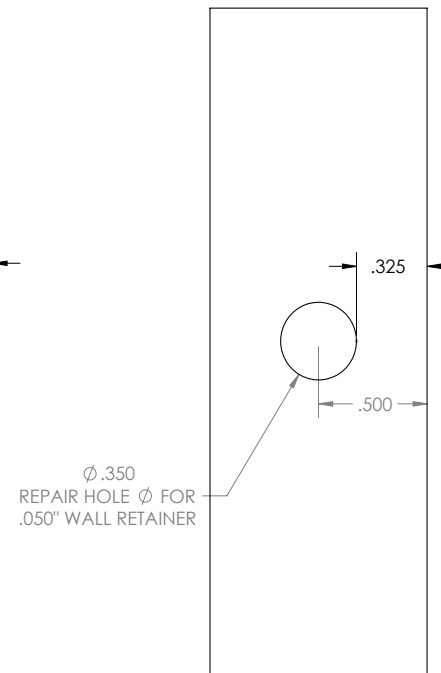
Ideal Design
 $e/D = 2.0$



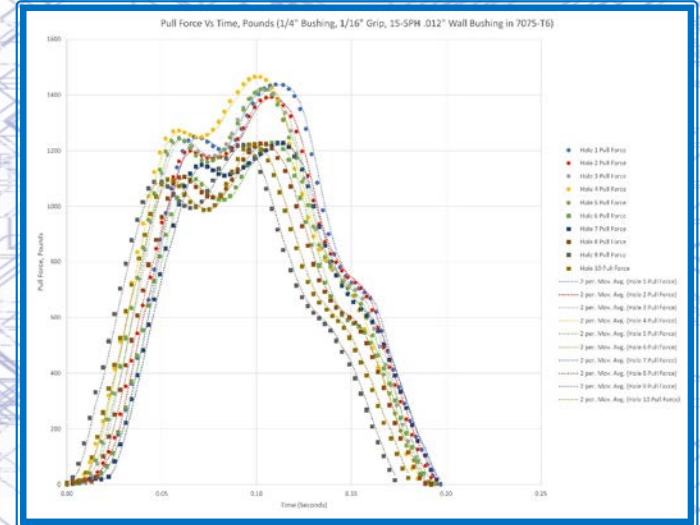
PartWorks
 $e/D = 1.85$



Status Quo
 $e/D = 1.43$



Process Verification - In Tool Measurement and Feedback

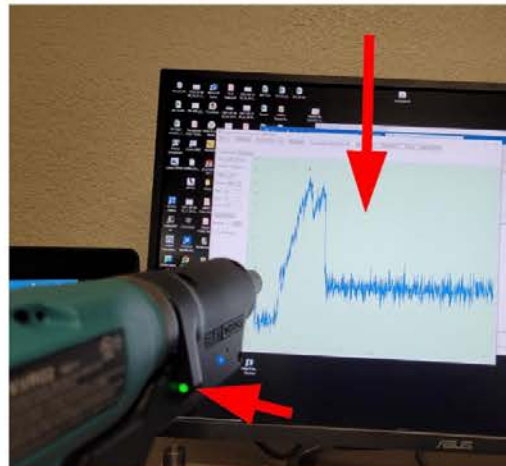


- Cold Expansion process parameters and pull-force documented in tool
- Pull-force data correlated to:
 - DIC
 - Test data
 - Material properties and geometries
- Good / Bad feedback provided to operator

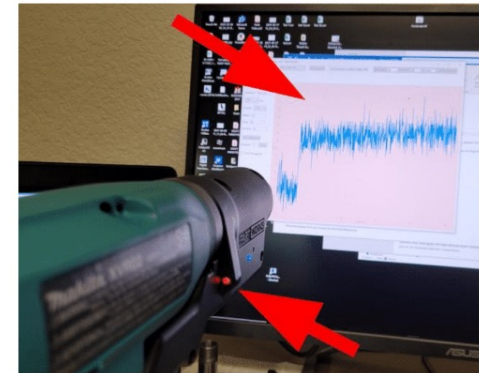
Process Verification - In Tool Measurement and Feedback



Handheld Puller with Process Control Electronics Incorporated



Process Control Software Identifying Successful Installation



Process Control Software Identifying Unsuccessful Installation with LED and Red Graph

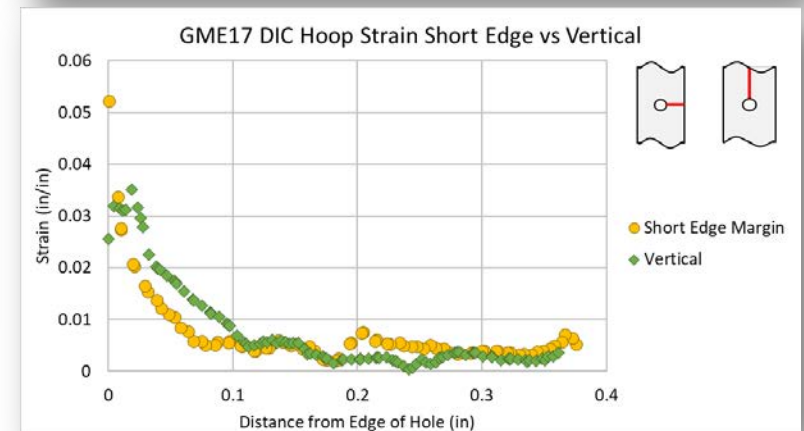
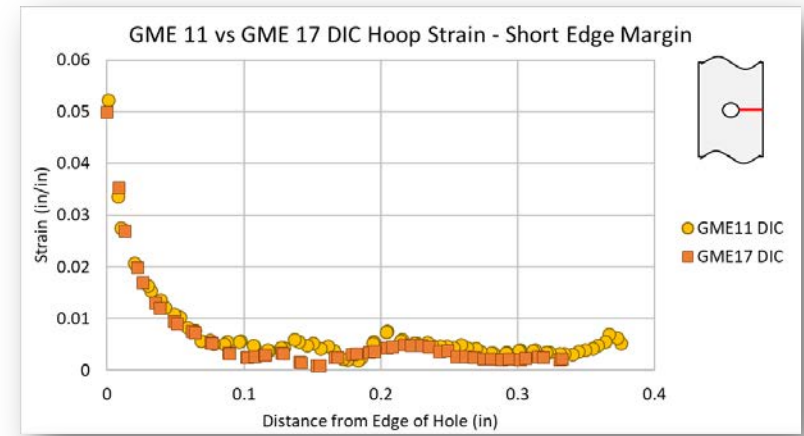
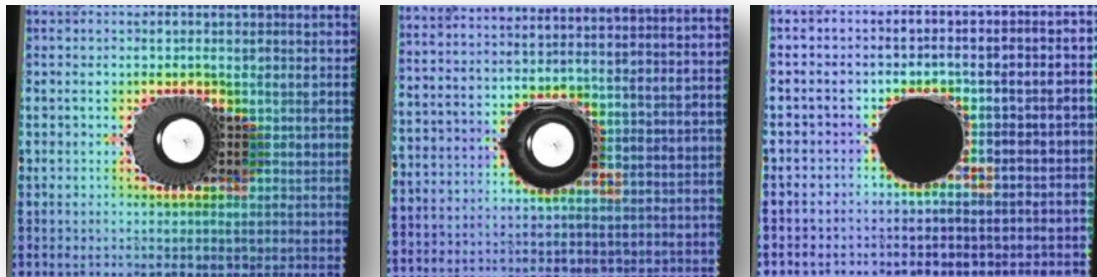
USAF Test Program

- Process Validation – FEA, Digital Image and X-Ray Diffraction

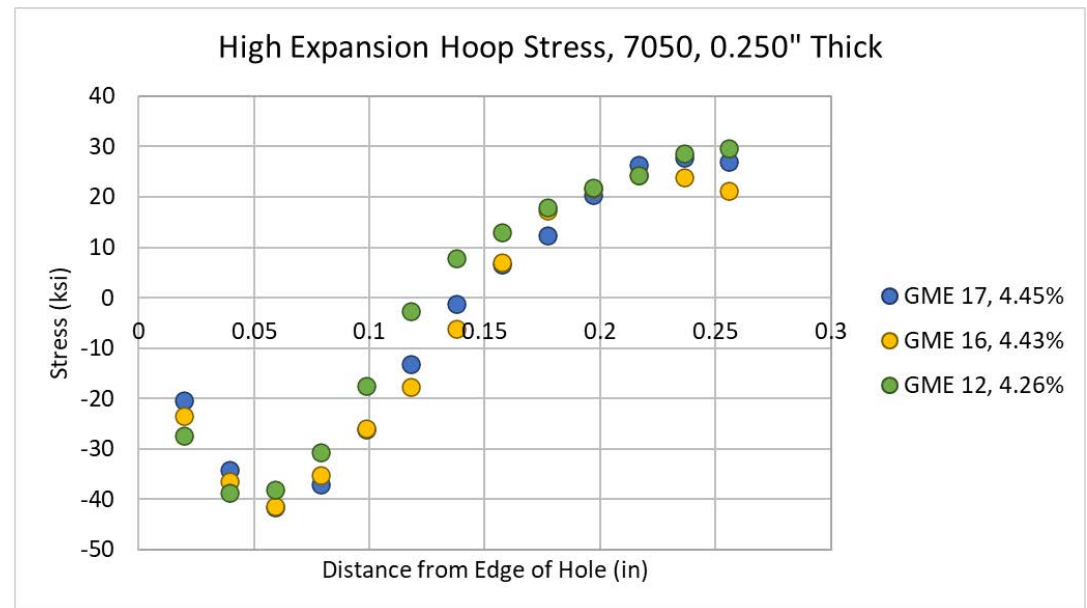
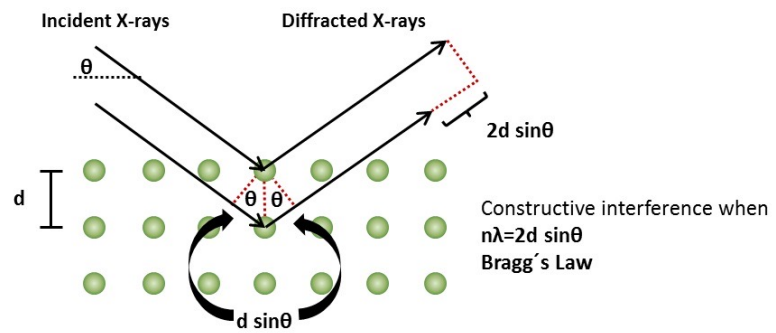
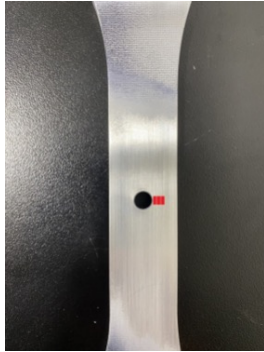
In Situ Process Validation

Residual Strain Visualization with DIC

- Image Capture: Before, during and after repair
 - On-tool image capture
- DIC used to correlate residual strain with FEA
- Will also be correlated to X-Ray diffraction

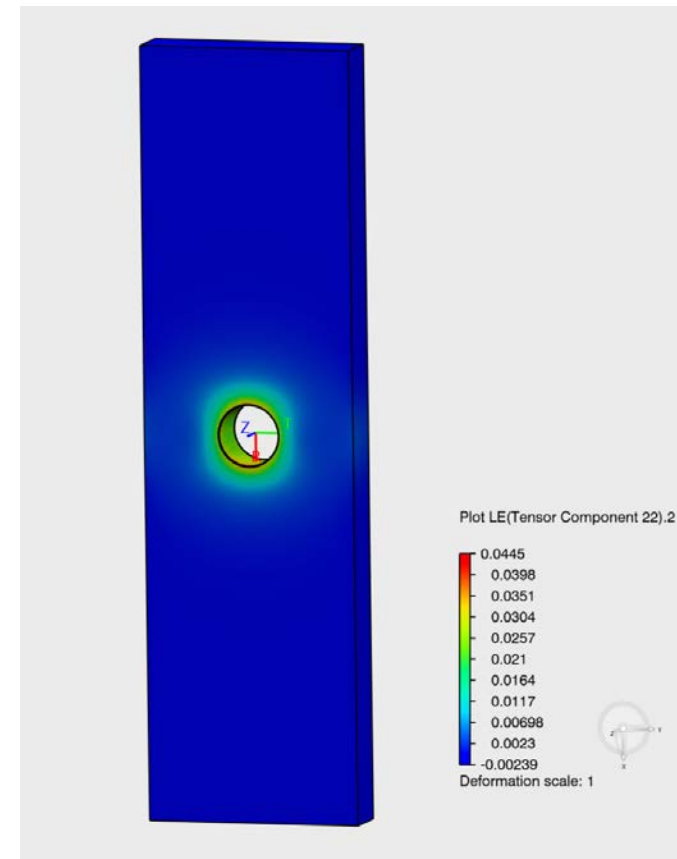
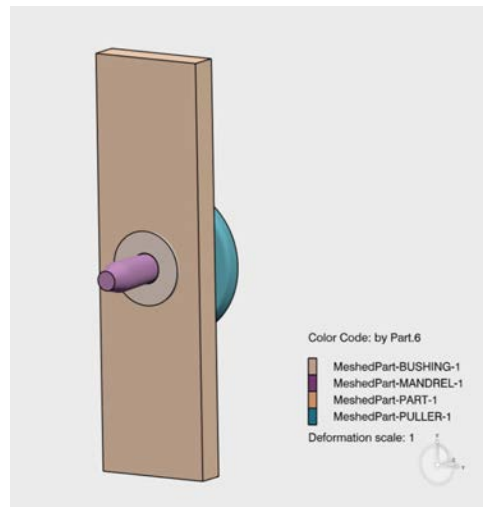


X-Ray Diffraction



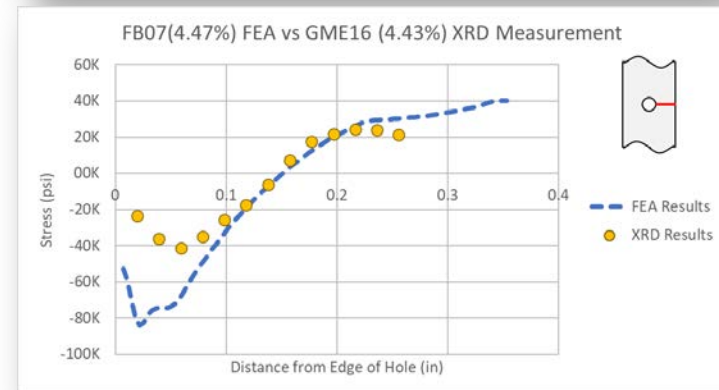
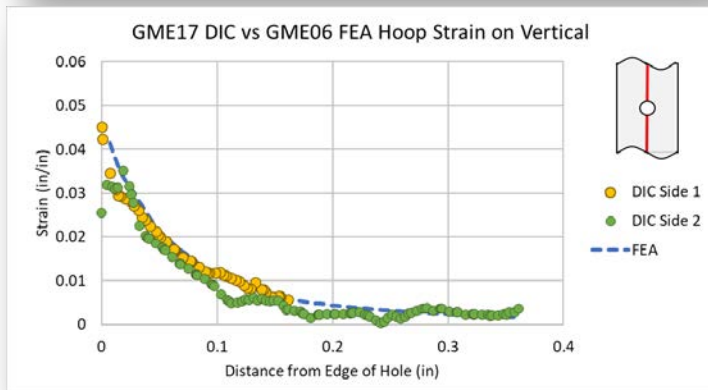
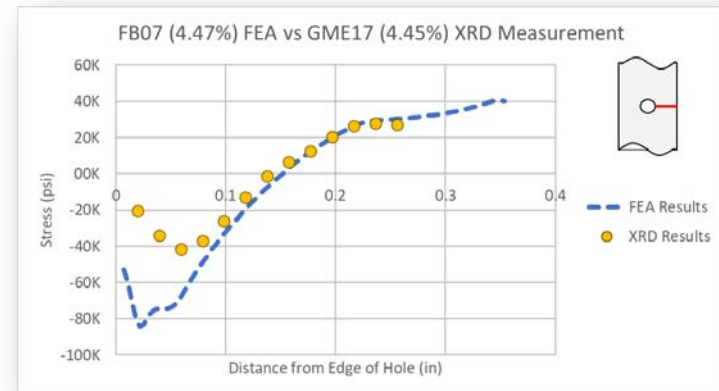
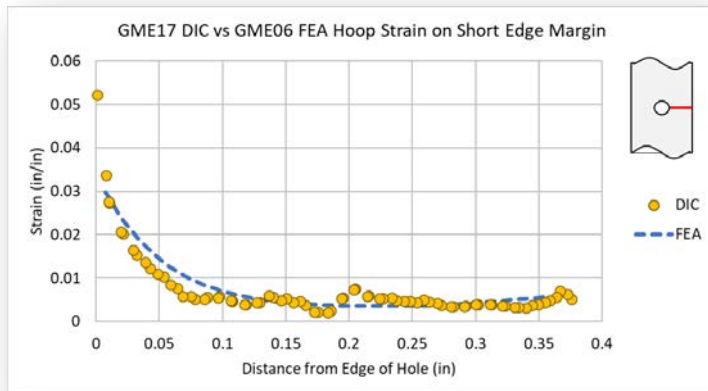
FEA - Process Simulation

- 3-D Pull Through Model
- Elastic-Plastic Properties of the Material
- Contact Modeled
- Explicit Method



USAF Test Program

- Correlation – FEA, Digital Image and X-Ray Diffraction



USAF Test Program

- Testing
 - Corrosion
 - Fatigue

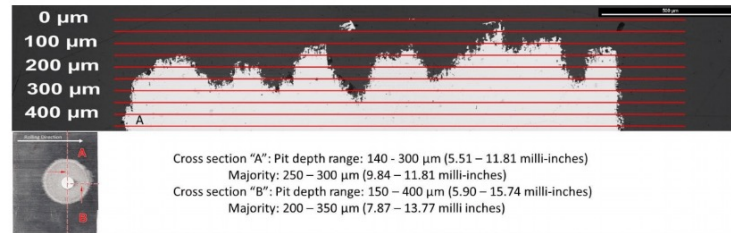
Corrosion Protocol Development



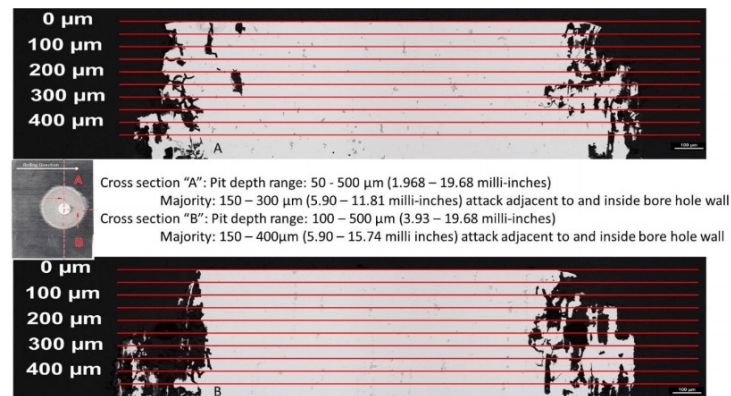
Figure 6 (L) Representative image of a multihole protocol development specimen taped off to expose one bore hole for corrosion testing; (C) Representative image of a single hole protocol development specimen taped off to expose one bore hole for corrosion testing; (R) Representative image of a dog bone fatigue test specimen taped off to expose the bore hole for corrosion testing (note: only top 2/3 of dog bone visible in scan image, although entire dog bone was taped).

- NaCl and NaAlO₂ solution
- Dogbones masked with electroplaters tape
- 0.25 in dia. hole, 0.75 inch dia. surface exposure each side of dogbone

Corrosion Protocol Development



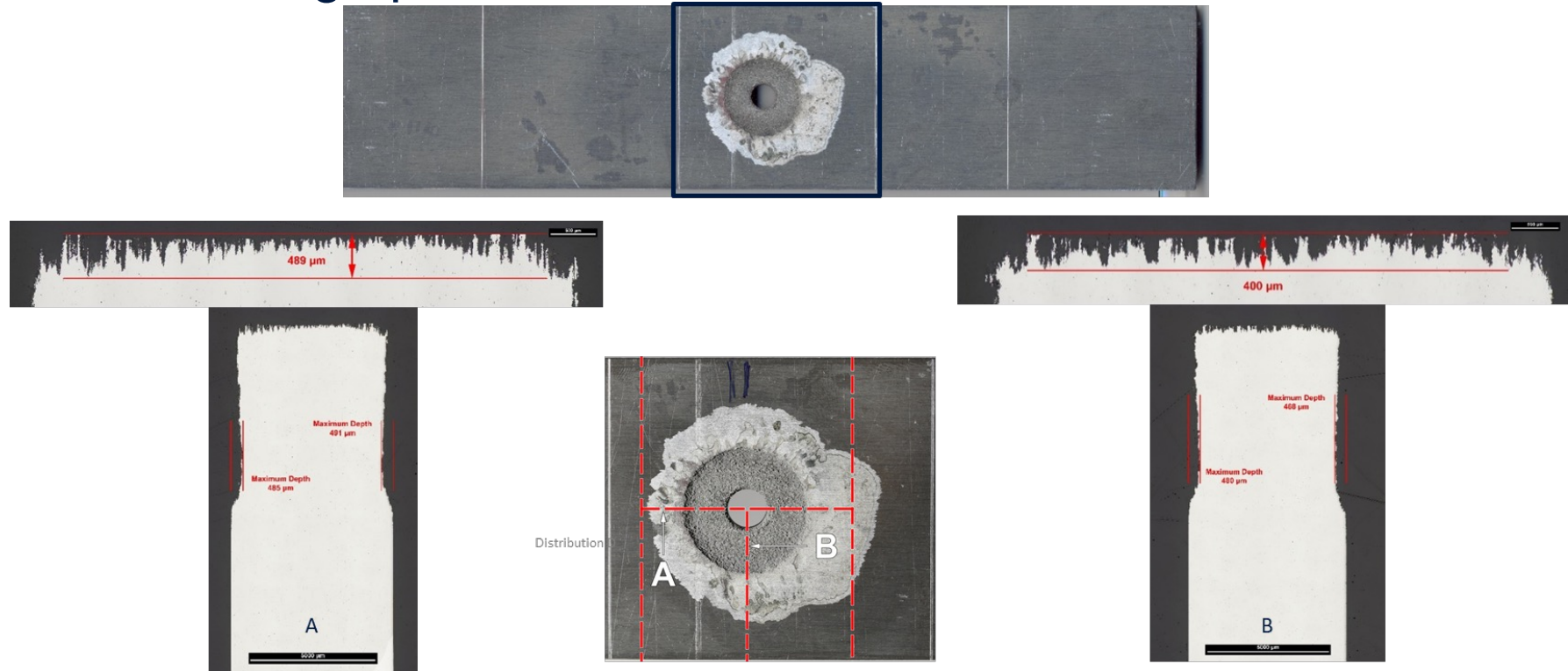
0.06 thick 7050 – 120 hour corrosion protocol



0.06 thick 2124 – 72 hour corrosion protocol

Corrosion Protocol Development

Metallographs of Plate Surface and Fastener Hole Wall



Fatigue Test Program

Load Spectrum	Parent material
F-35	7050-T7451
F-35	2124-T8151
F-22	2124-T8151
F-22	7050-T7451

Baseline – open hole, no corrosion

Corroded - open hole

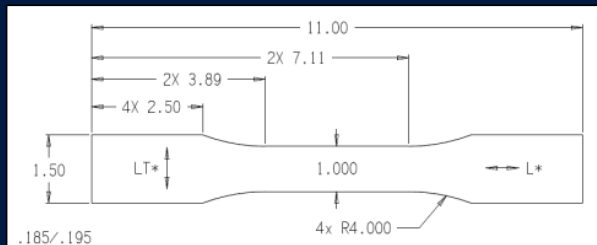
Repair - no corrosion

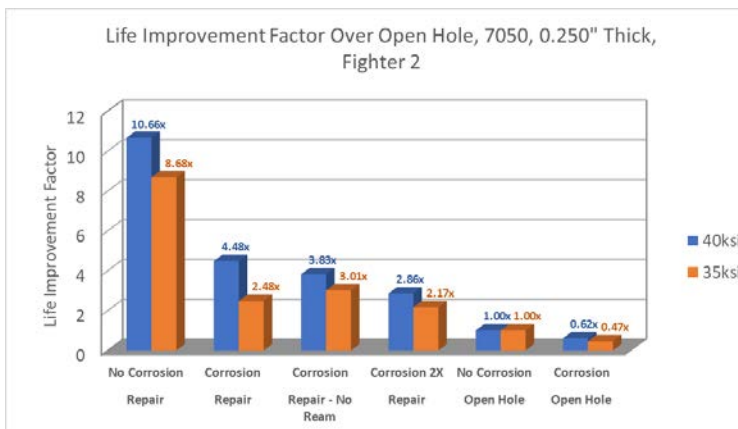
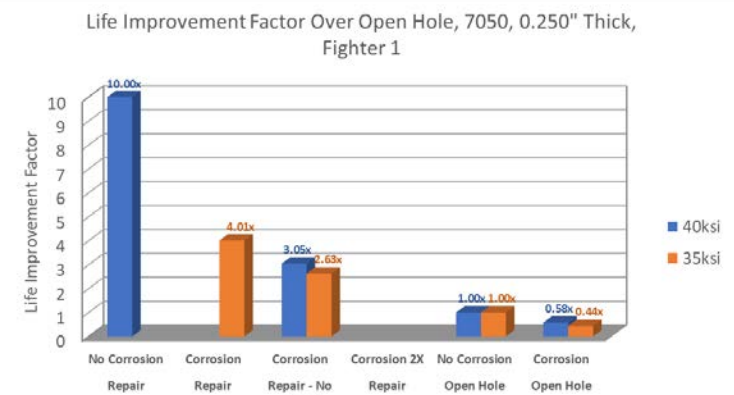
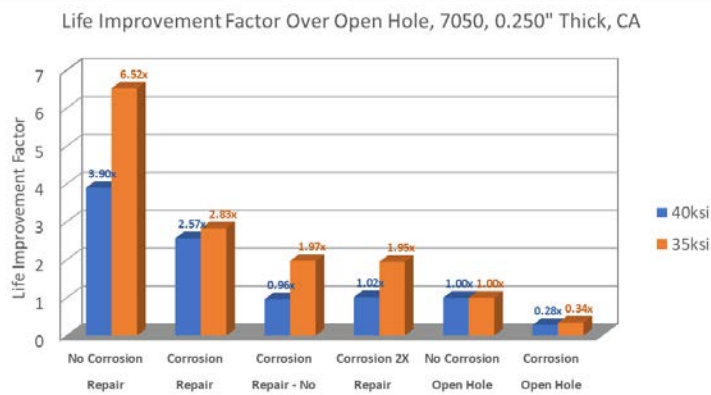
Corroded, reamed repaired

Corroded, reamed, repaired, corroded

Corroded, repaired (no ream)

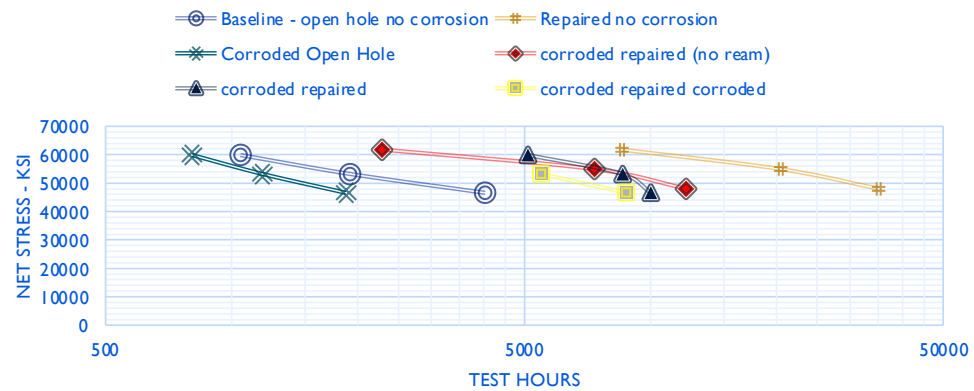
Repaired when new, cycle for 10K cycles, then corrode and cut coupon in half to look for potential corrosion between bore of hole and barrel of thin wall bushing





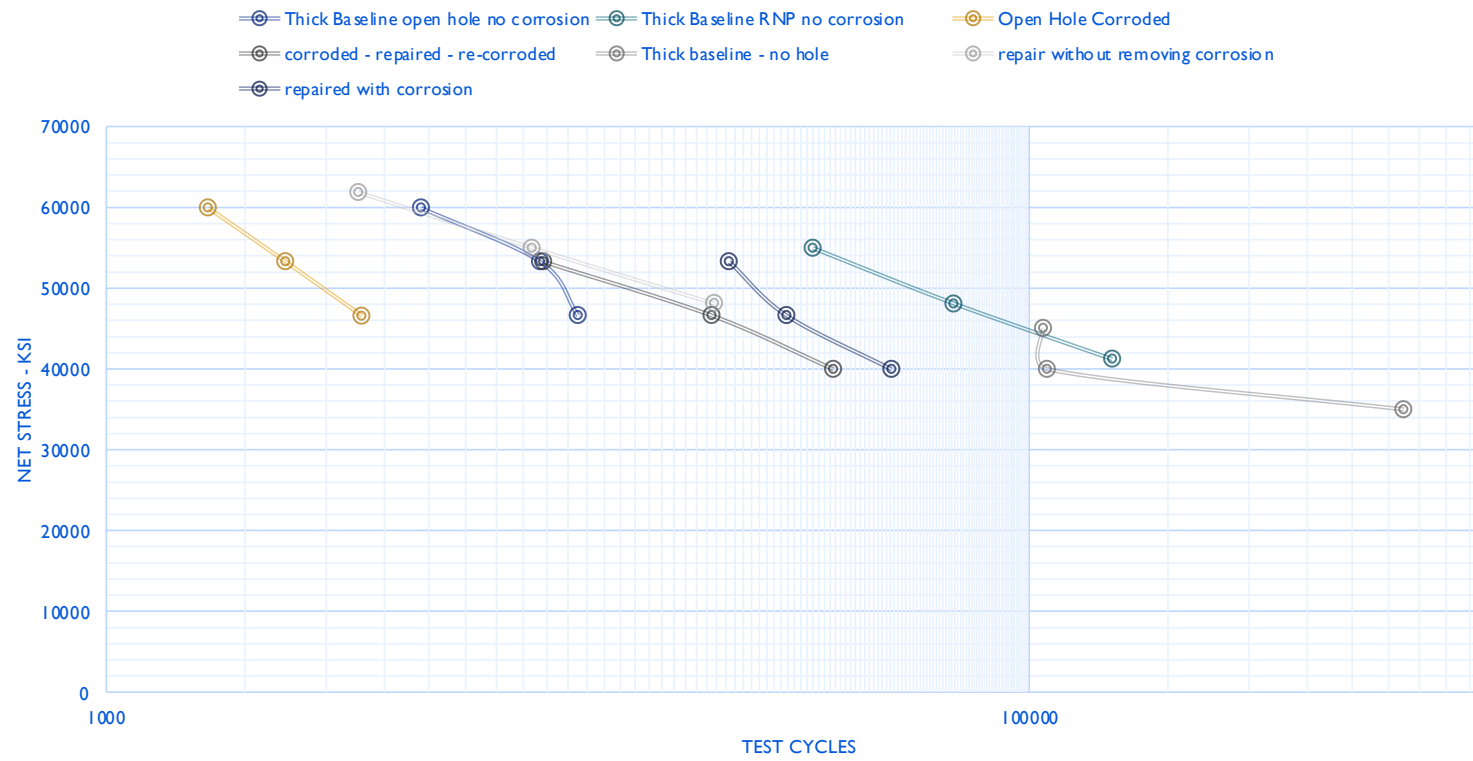
Fatigue Testing

7050 Thick F-35 Spectrum - A



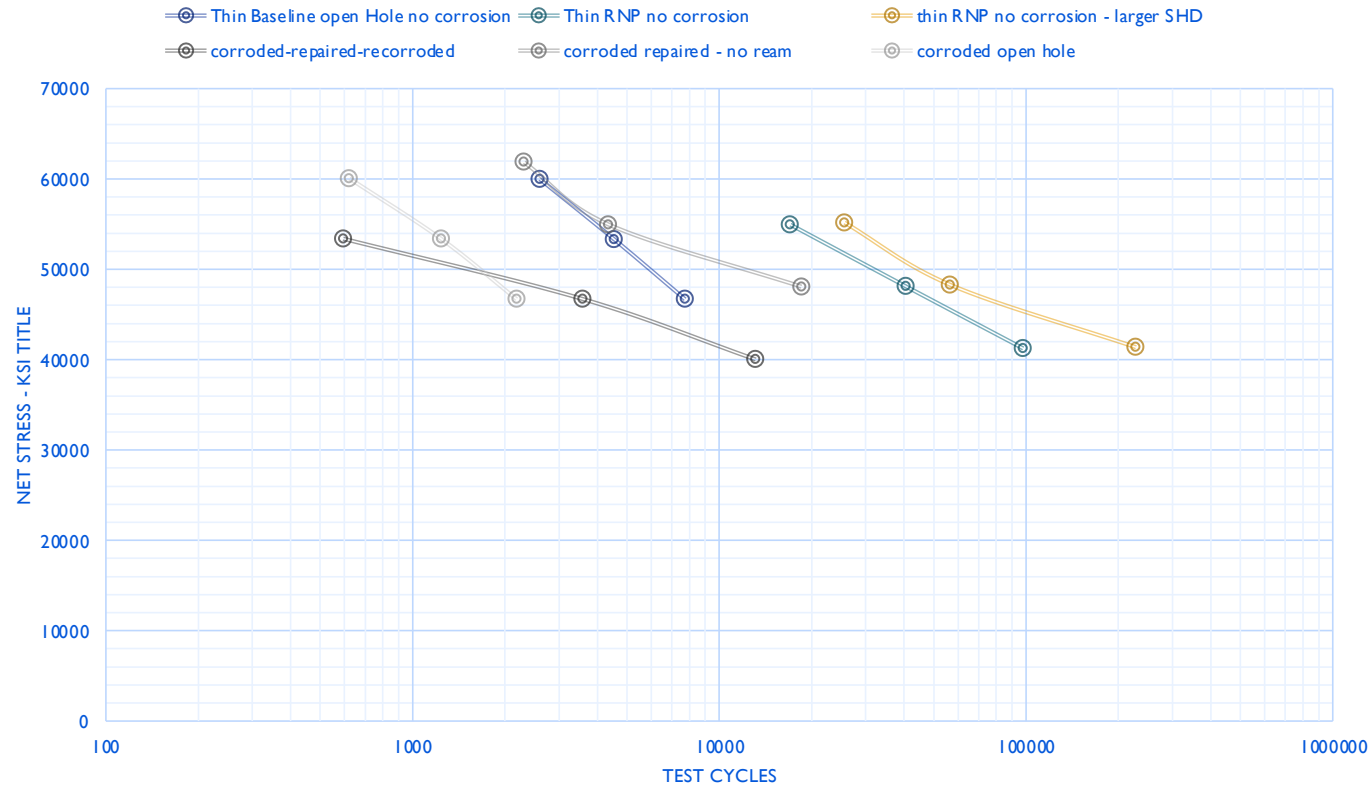
Fatigue Testing

7050 Thick Constant Amplitude - C



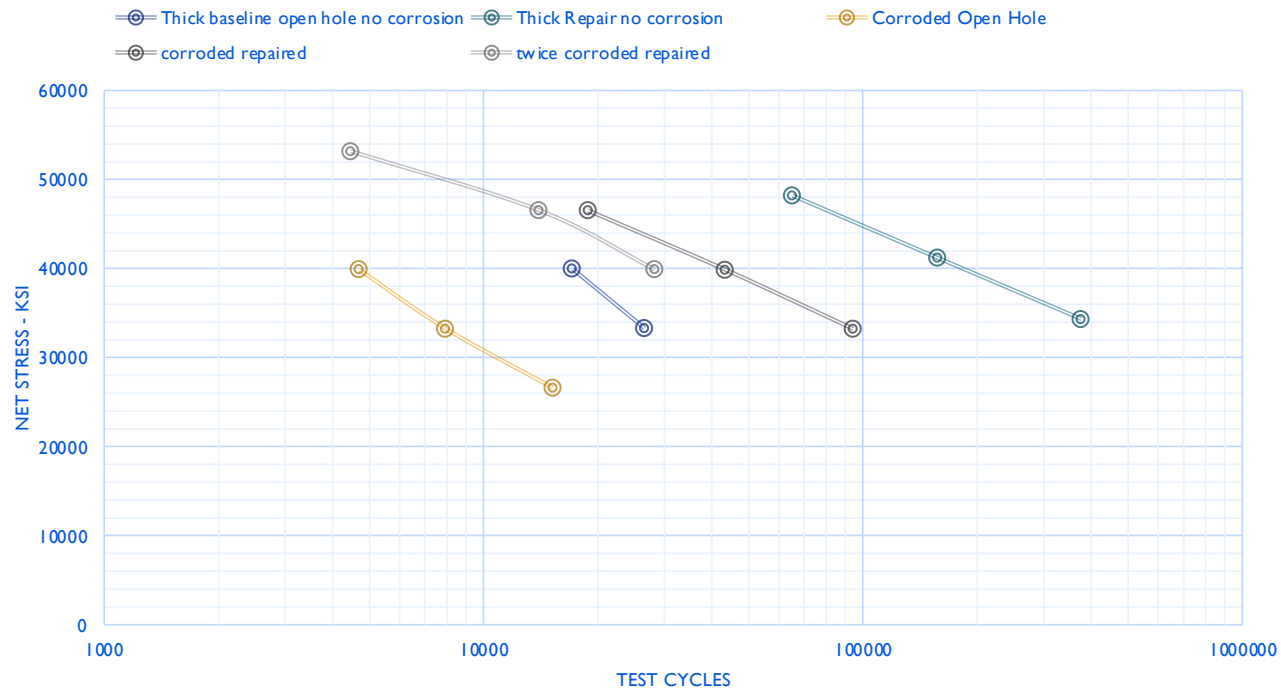
Fatigue Testing

7050 Thin Constant Amplitude - C

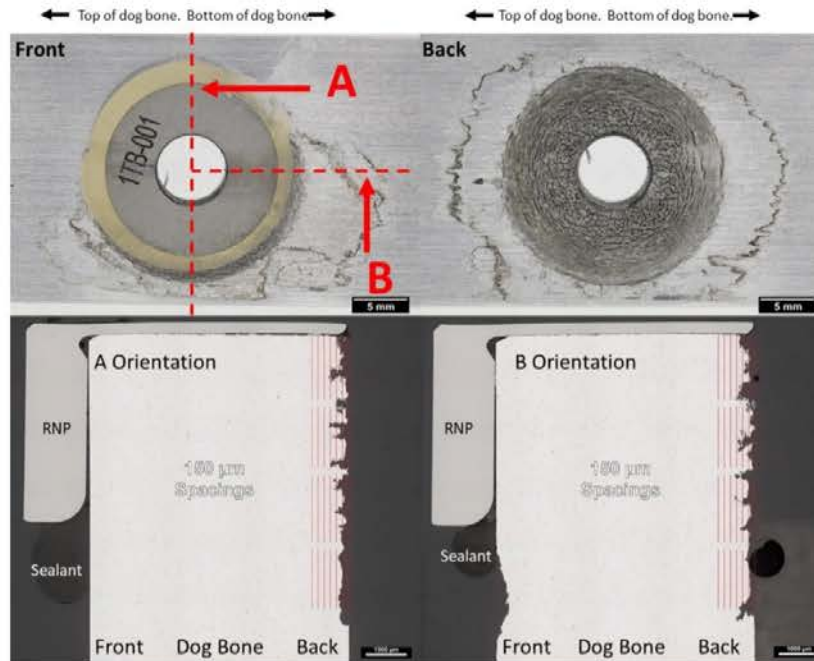


Fatigue Testing

2124 Thick Constant Amplitude - D



Adhesive - Galvanic Barrier



7050 material – 120 hour corrosion protocol

Goal

- Contaminant tolerant
- Pre-applied (murphy proof for user)
- Cold expansion compatible
- Sufficient mechanical properties
- Dielectric Insulator
- Impervious to moisture
- Permanent installation

Galvanic Barrier

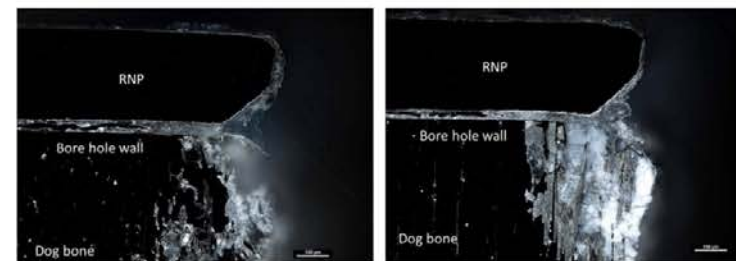
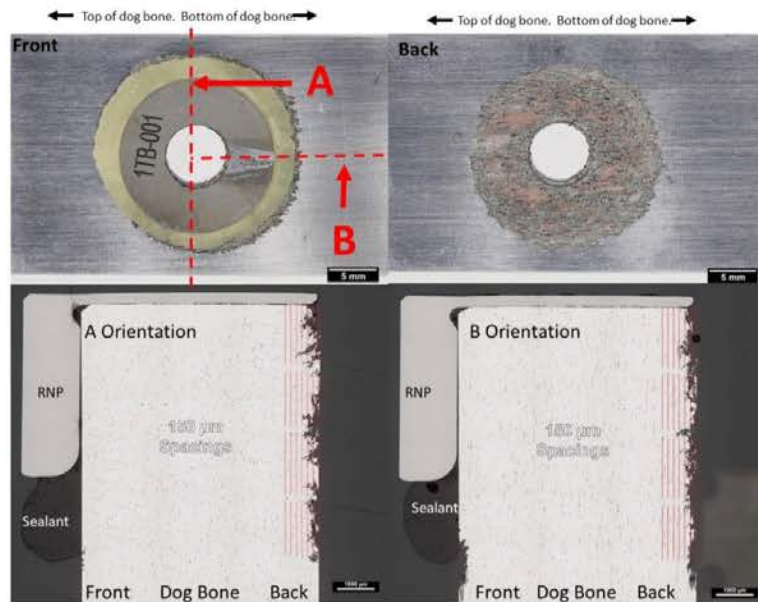


Figure 24. Dark field image of RNP-sealant/bore hole wall interface on back of dog bone. (Left) Orientation "A". (Right) Orientation "B".

The 120 hour corrosion of the repaired and corroded AA2124-T8151 dog bone exhibited no observable corrosion attack beneath the RNP-sealant/bore hole wall interface, except for attack from the surface undercutting the sealant on the front of the dog bone in both orientations as well as on the back of the dog bone at the RNP-Sealant/bore hole wall interface.

2124 material – 120 hour corrosion protocol

Augmented Reality

Will contain video of Georgia Tech AR and a generic piece of commercial aircraft fuselage section

Project Goals

- Simplified / Standardized Repair
- Preserve edge margin
- Provide fatigue life benefit
- Protect against undetected or missed damage
- Reduce analysis time
- Increase fleet readiness
- Allow credit for engineering residual stress
- Save cost

Considerations for New Production



F-18 program spends \$690M / year on corrosion (30% of total maintenance budget)

Hybrid structure of some of the newest USAF aircraft have similar corrosion problems



Prevent today's corrosion problems from becoming tomorrow's.

PartWorks solution incorporated in new production can mitigate corrosion in fastener holes

Thank you



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