Reinventing the Future of Cold Expansion™

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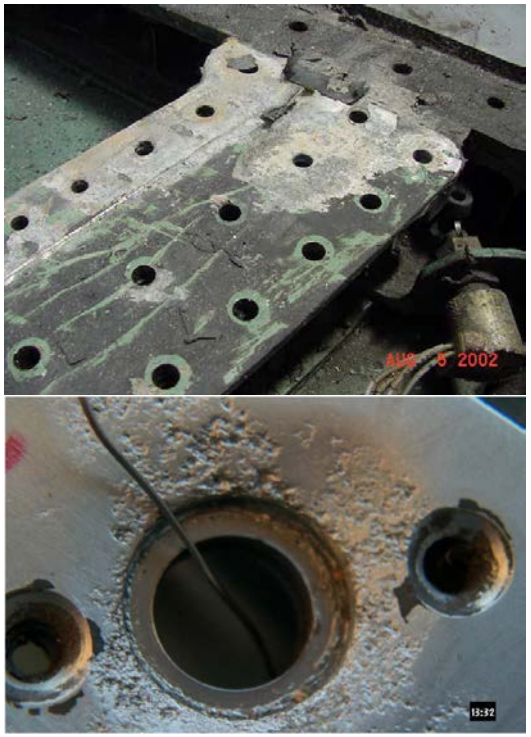
PART WORKS

Bolt Hole Corrosion and Fatigue Damage Repair in Hybrid Structure

Vertical Flight Society Forum 79
Presented by Dale Manning
May 2023

Galvanic Corrosion of Hybrid Structure

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



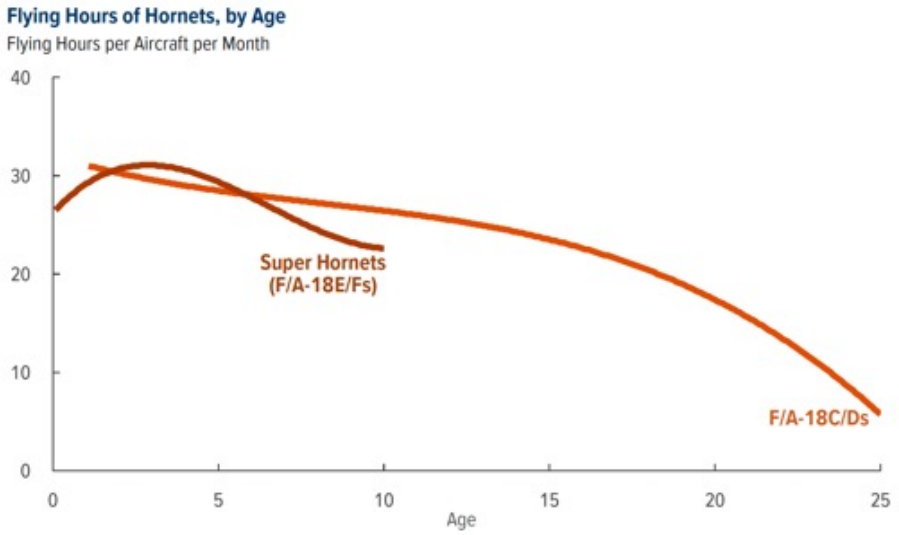
From "In-service Corrosion Issues in Sustainment of Navy Aircraft" briefing, R. Mendoza, Aug 2012

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

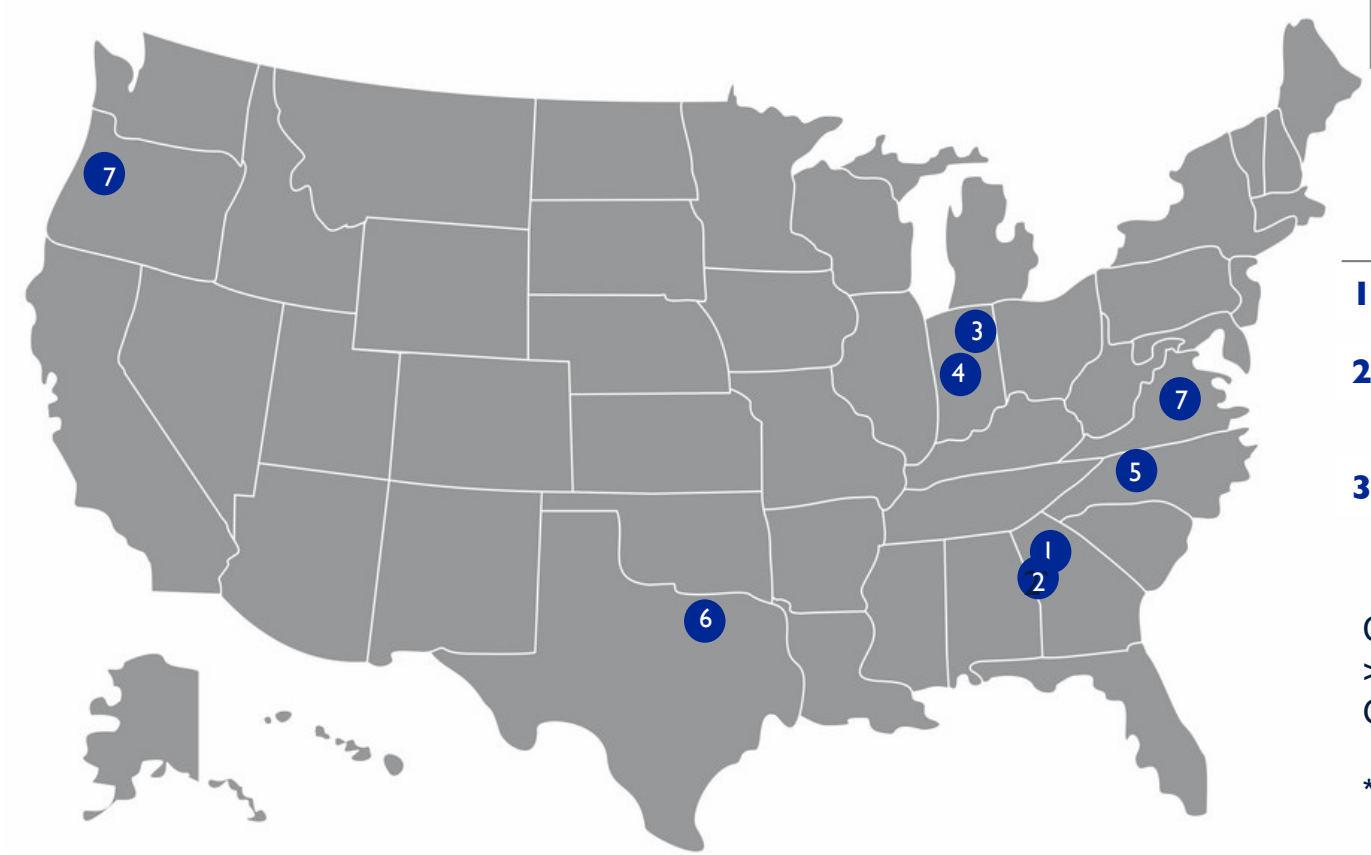
"Between FY17 and FY20, corrosion costs accounted for $2,086,796,553, amounting to 29.4 percent of the total maintenance cost for [F-18 C-G] aircraft."

F-18: Canary in the Coal Mine

- CBO Study (Feb 23): Super Hornet Availability at 10 years are 18% less than Older F/A-18 Models.
- "DoN noted that many factors contributed to the differences in availability… including the greater levels of galvanic corrosion arising from the greater use of composite metals in Super Hornets.
- V-22 and CH-53K have similar material stack-ups



Corporate Overview



PART WORKS

IS A WHOLLY OWNED SUB OF PHX HOLDINGS

1 PHX Holdings
Atlanta, Georgia

2 PartWorks
PSG* Plants 1& 2
Atlanta, Georgia

3 PSG* Plant 3 Indiana
Fort Wayne, Indiana

4 GTC Machining
Indianapolis, Indiana

5 PSG* Plant 4 NC
Charlotte, NC

6 PSG* Plant 5 TX
Dallas/Ft Worth, TX

7 PartWorks
Field Offices
Alexandria, VA
Seattle, WA

Combined annual revenue > $125M
>300+ employees, 400,000+ sq. feet
GTC is AS9100D, ITAR

*PSG=Phoenix Stamping Group:
ISO 9001-2015

USAF Test Program

Carried out in Conjunction with:

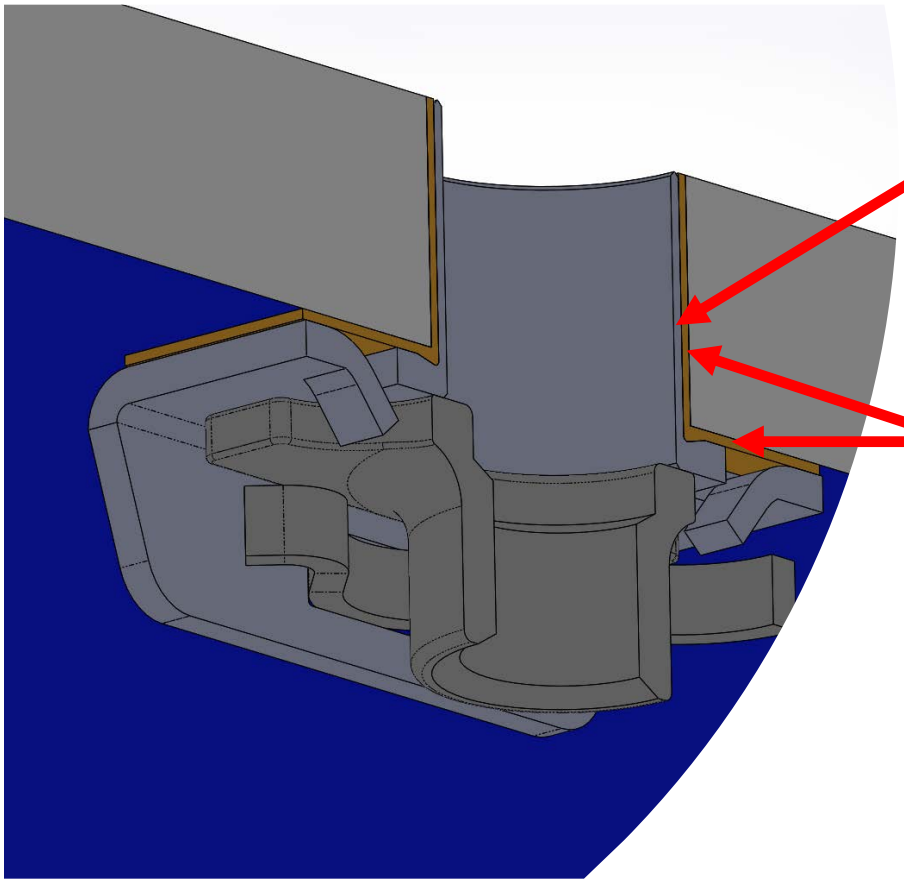
University of Dayton Research Institute (UDRI)
Goose Meadow Engineering at Montana State University
Georgia Tech

- Developed methodology to recreate fleet level corrosion in laboratory setting
- Assess fatigue performance of repair to corroded and uncorroded baselines
- Create FEA models for design evaluation and validate models by comparison to DIC and X-ray diffraction.
- Develop Adhesive to prevent or arrest corrosion and ease installation
- Develop methods to seamlessly track repairs and record relative QA data

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



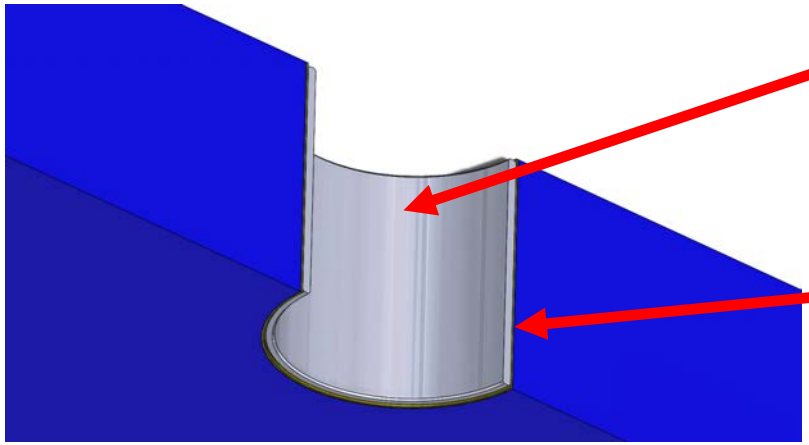
Thin wall

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

Pre-applied Adhesive (Development item)

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

PartWorks Bushing Repair



Thin wall

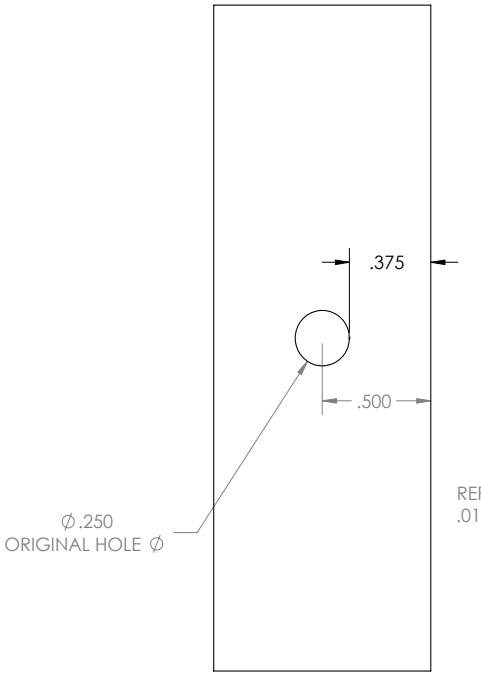
- **CRES Bushing barrel**
- **Minimizes material removal**
- **Maximizes e/D**
- **Maximizes cold expansion to the structure**

Adhesive

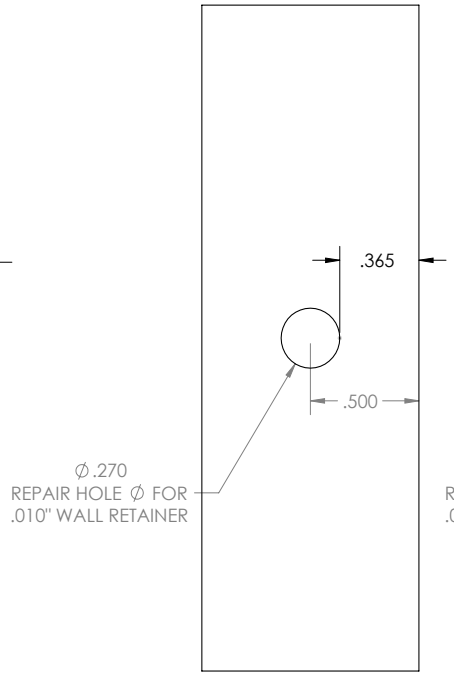
- **Galvanic barrier**
- **Minimal surface preparation**

Preserve Edge Margin

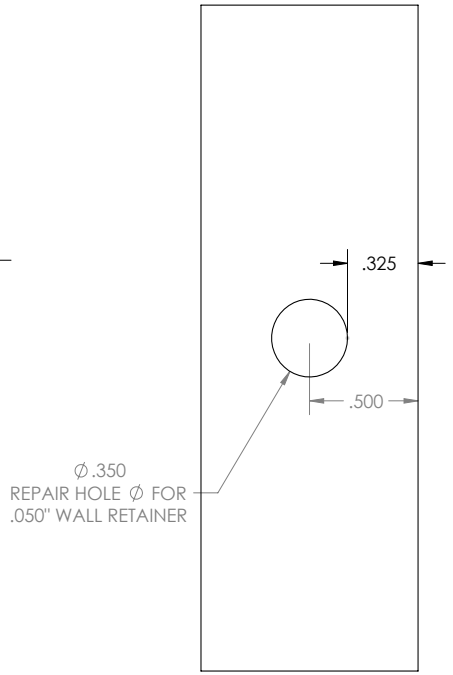
Ideal Design
e/D = 2.0



PartWorks
e/D=1.85



Status Quo
e/D = 1.43



- **Corrosion**
- **Fatigue**

Corrosion Protocol Development

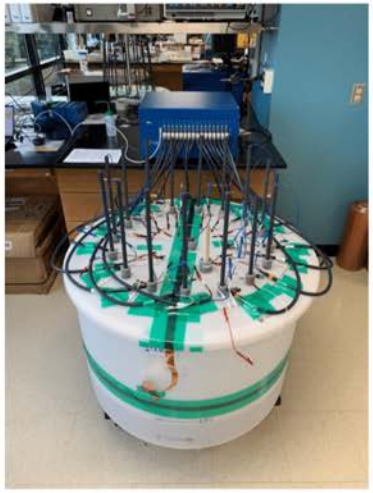
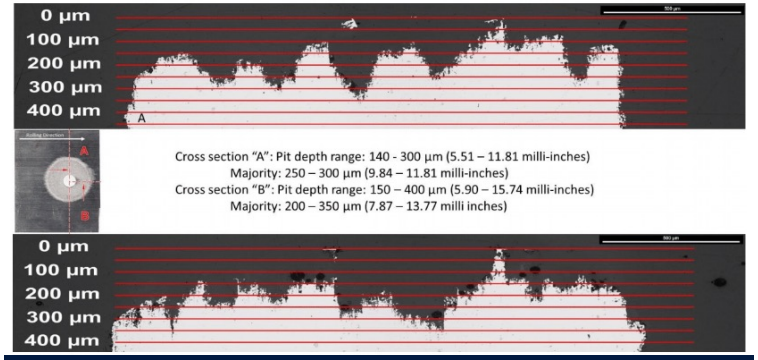


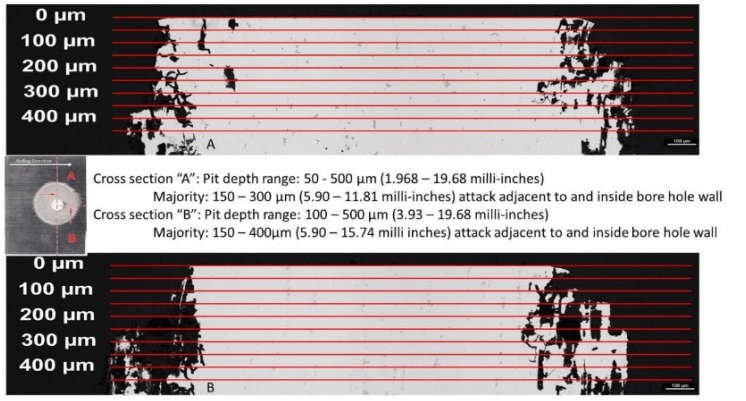
Figure 6 (L) Representative image of a multihole protocol development specimen taped off to expose one bore hole for corrosion testing; (C) Representative image of a single hole protocol development specimen taped off to expose one bore hole for corrosion testing; (R) Representative image of a dog bone 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
- Solution biased at 700mV

Corrosion Protocol Development

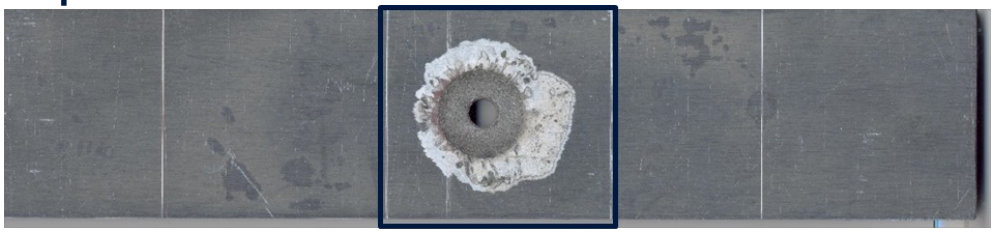


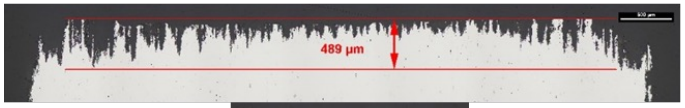
0.06 thick 7050 – 120 hour corrosion protocol

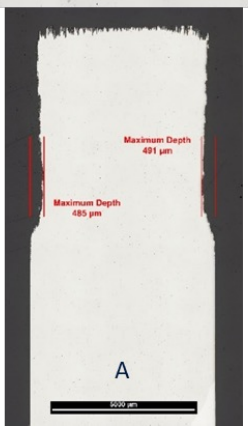


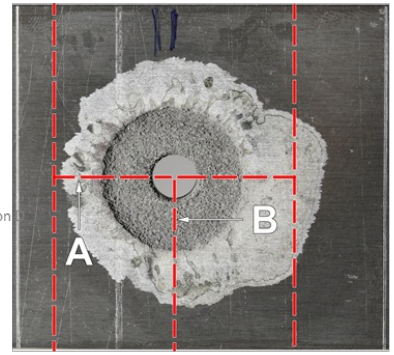
0.06 thick 2124 – 72 hour corrosion protocol

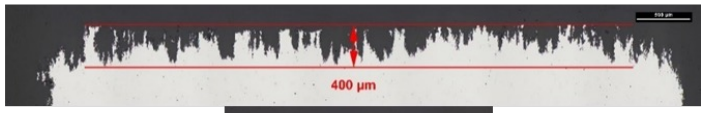
Metallographs of Plate Surface and Fastener Hole Wall

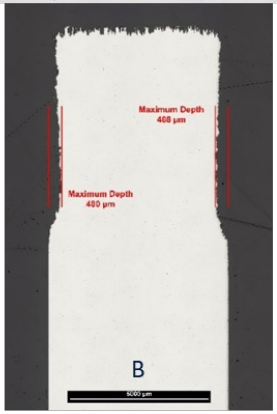




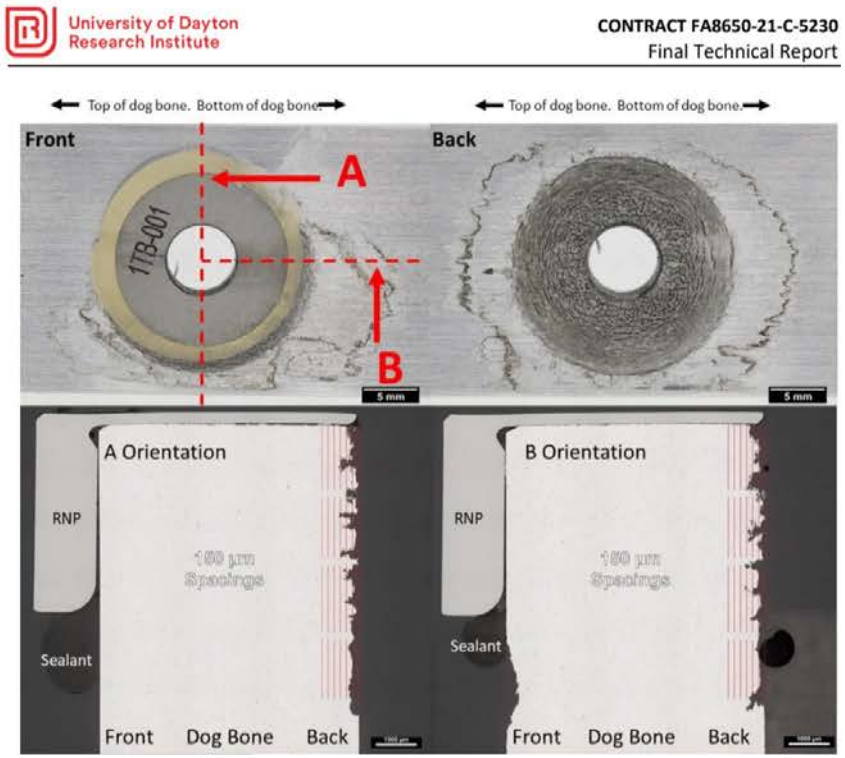








Adhesive - Galvanic Barrier

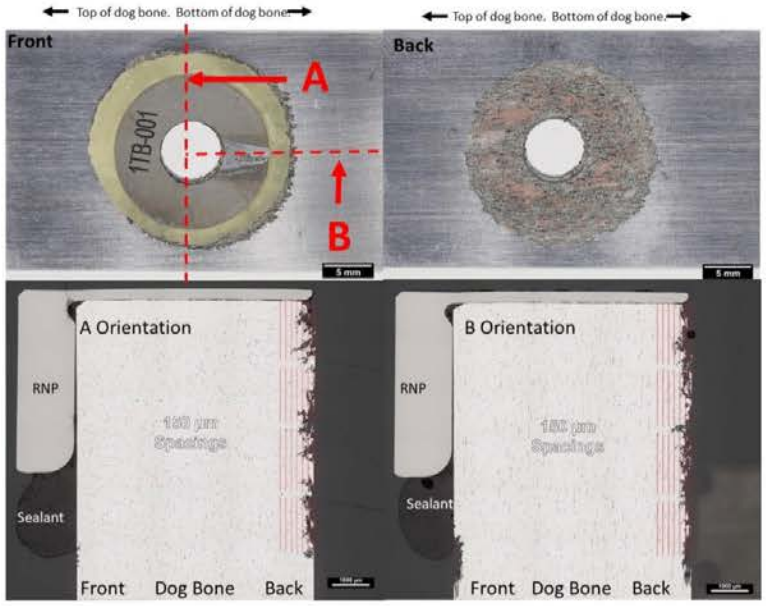


7050 material – 120 hour corrosion protocol

Goal

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

Galvanic Barrier



University of Dayton Research Institute
CONTRACT FA8650-21-C-5230
Final Technical Report

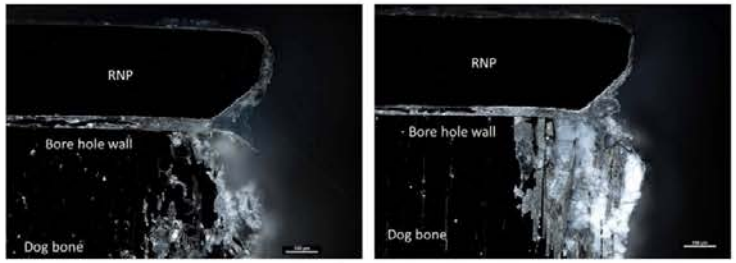


Figure 24. Dark field image of RNP-sealant/bore hole wall interface on back of dog bone. (Left) Orientation "A". (Right) Orientation "B".

2124 material – 120 hour corrosion protocol

Analytical and Experimental Methods

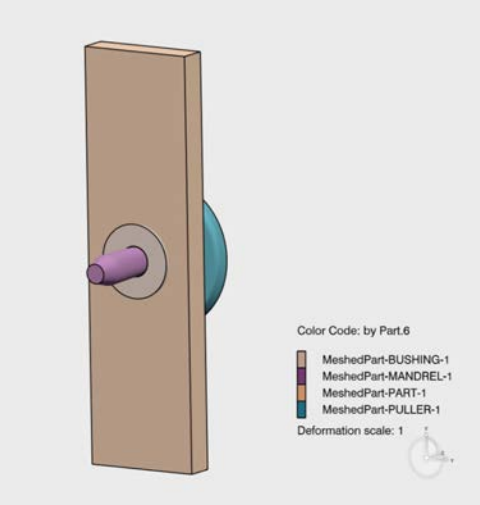
FEA

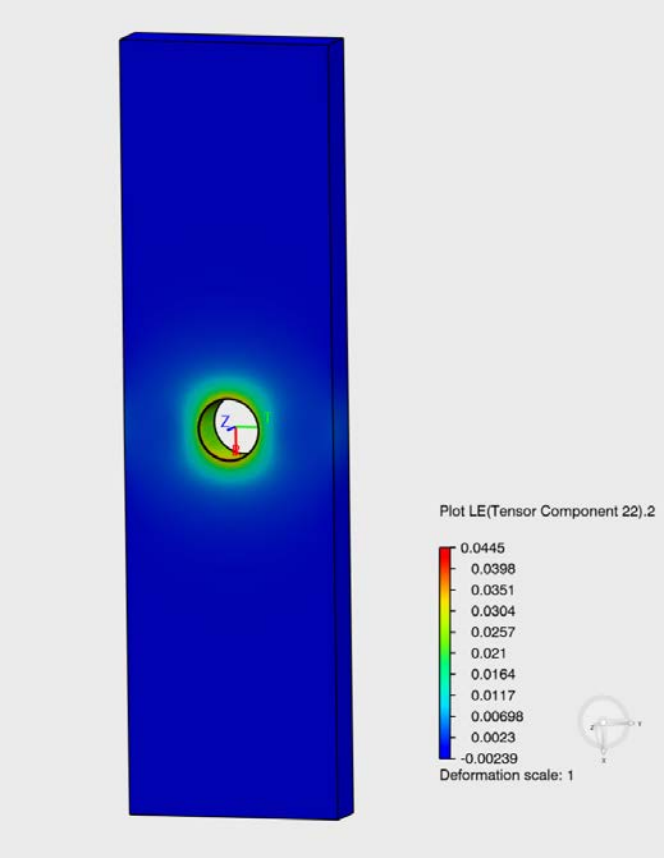
DIC

X-ray Diffraction

FEA - Process Simulation

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

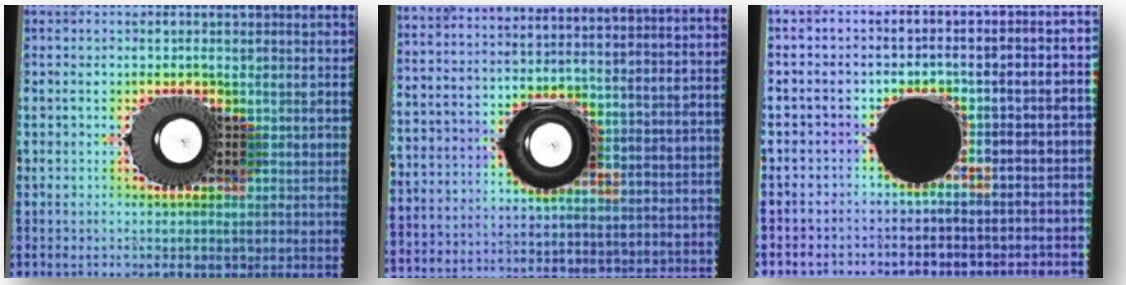


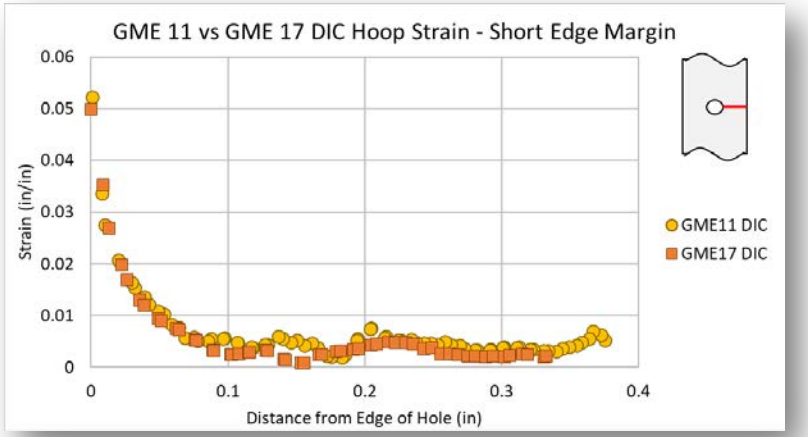


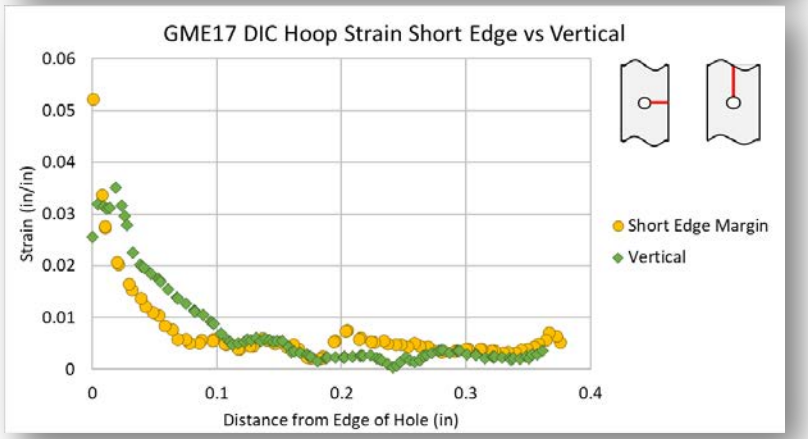
In Situ Process Validation

Residual Strain Visualization with DIC

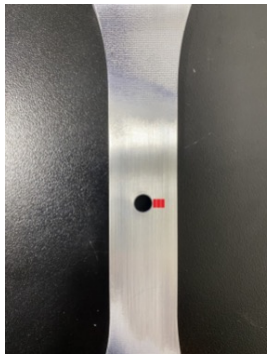
- Image Capture: Before, during and after repair
  - On-tool image capture
- DIC used to correlate residual strain with FEA
- Will also be correlated to X-Ray diffraction

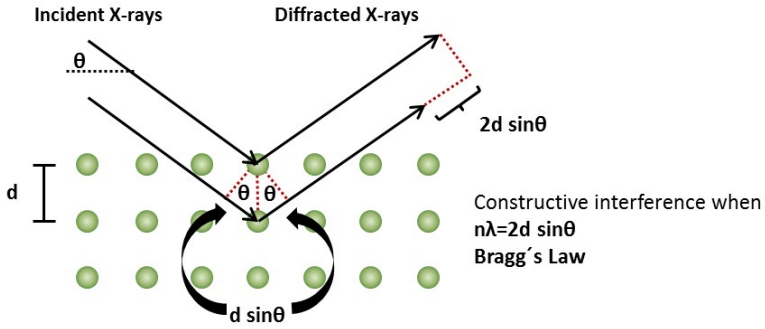


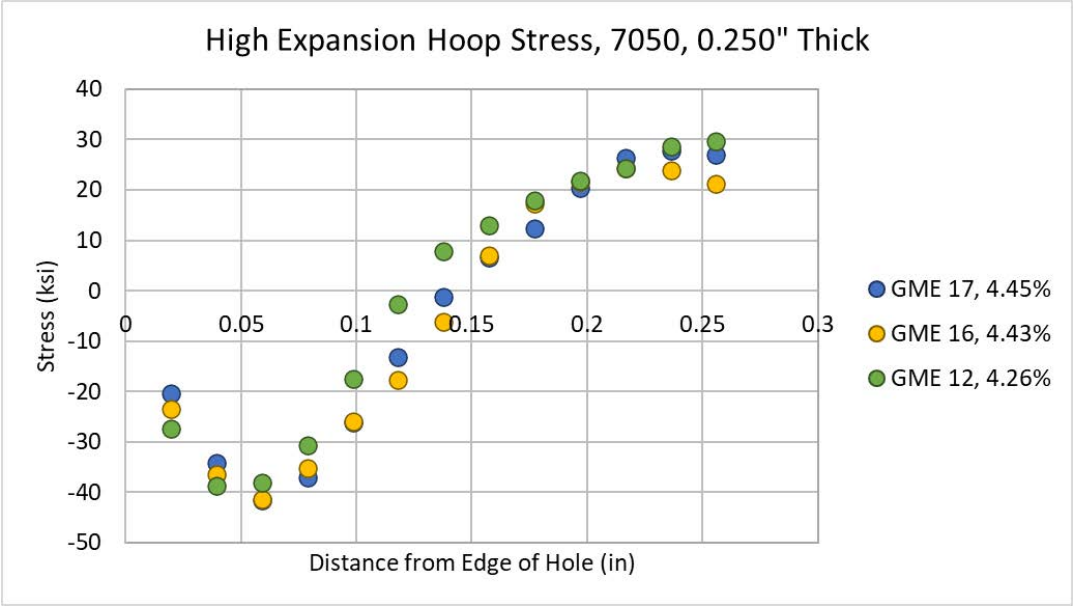




X-Ray Diffraction

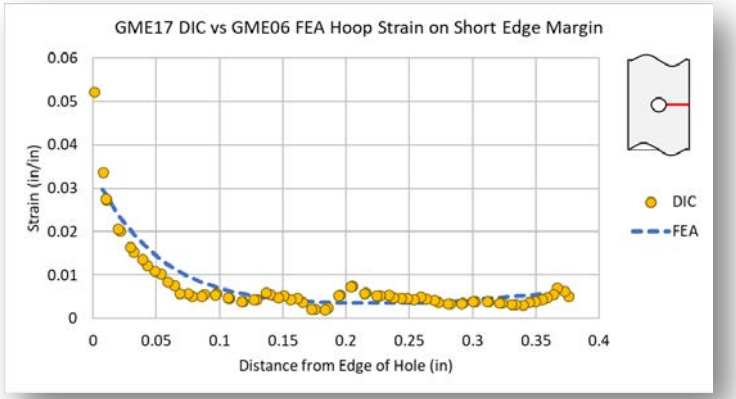


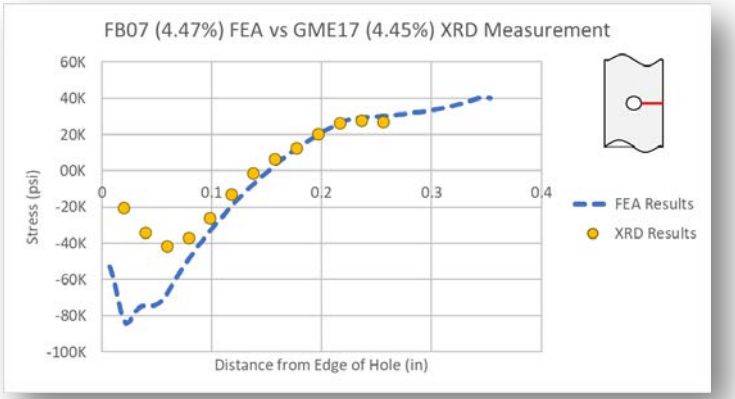


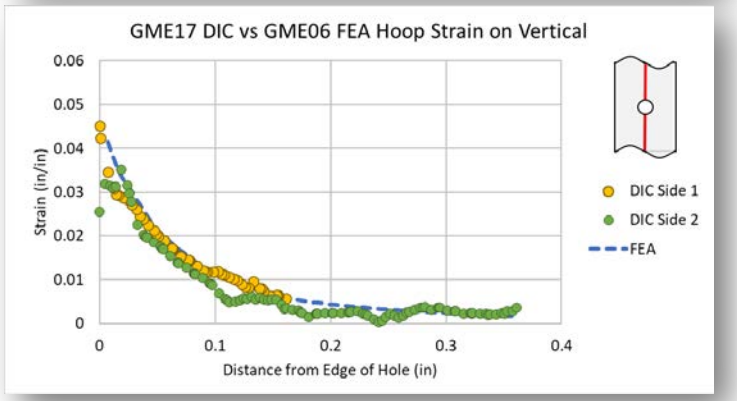


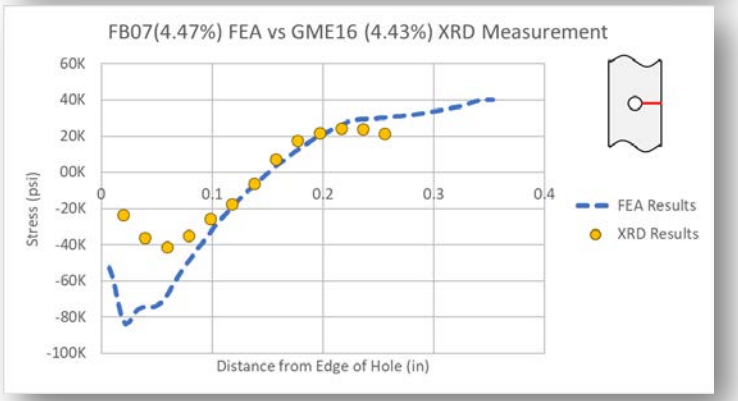
USAF Test Program

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



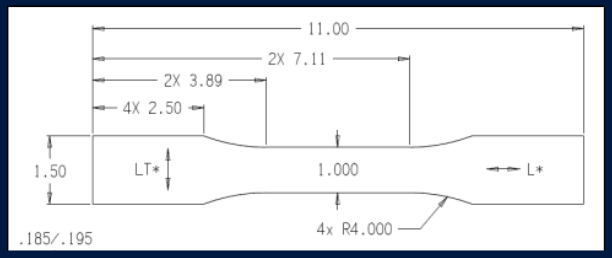






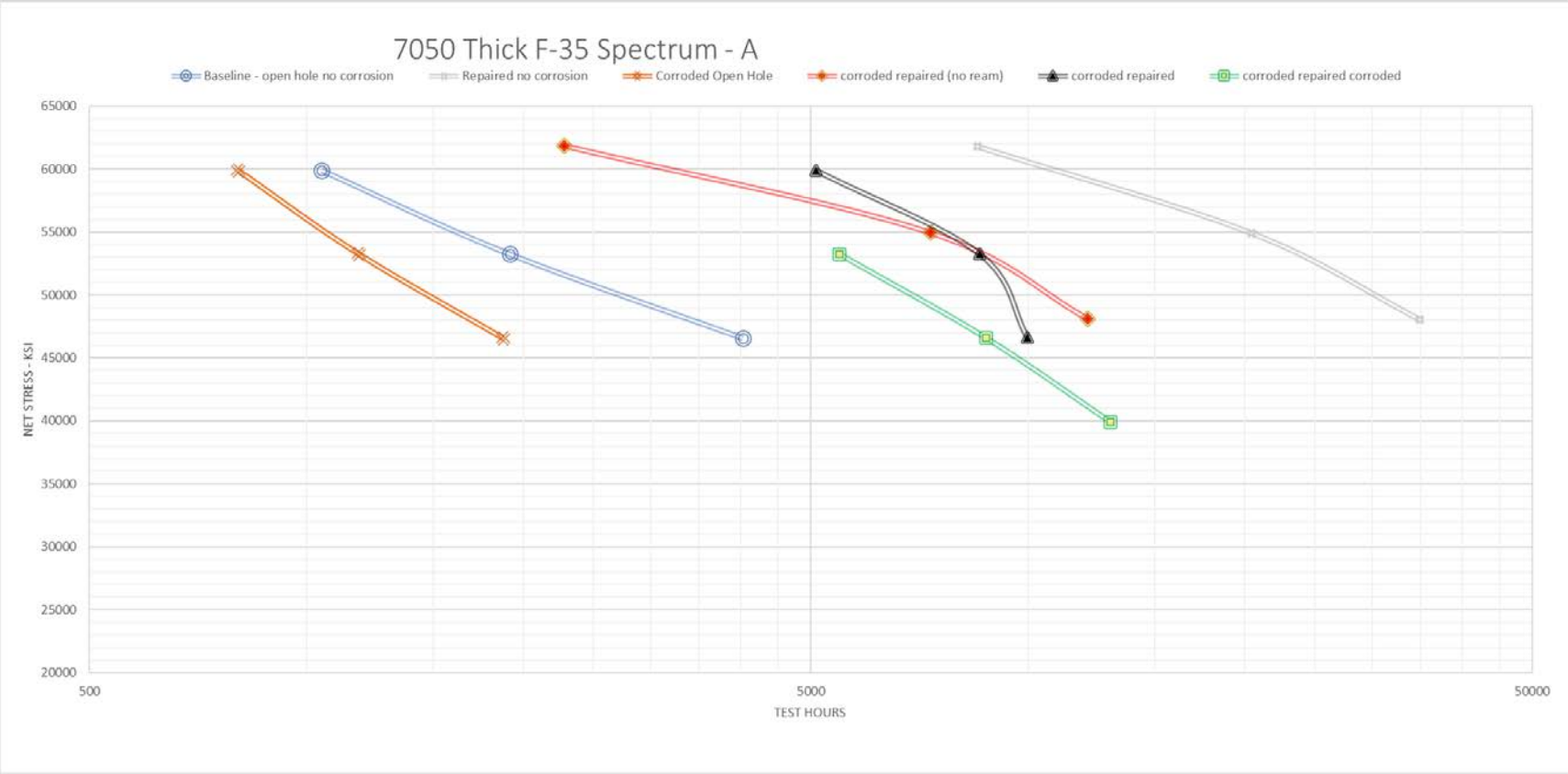
Fatigue Test Program

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

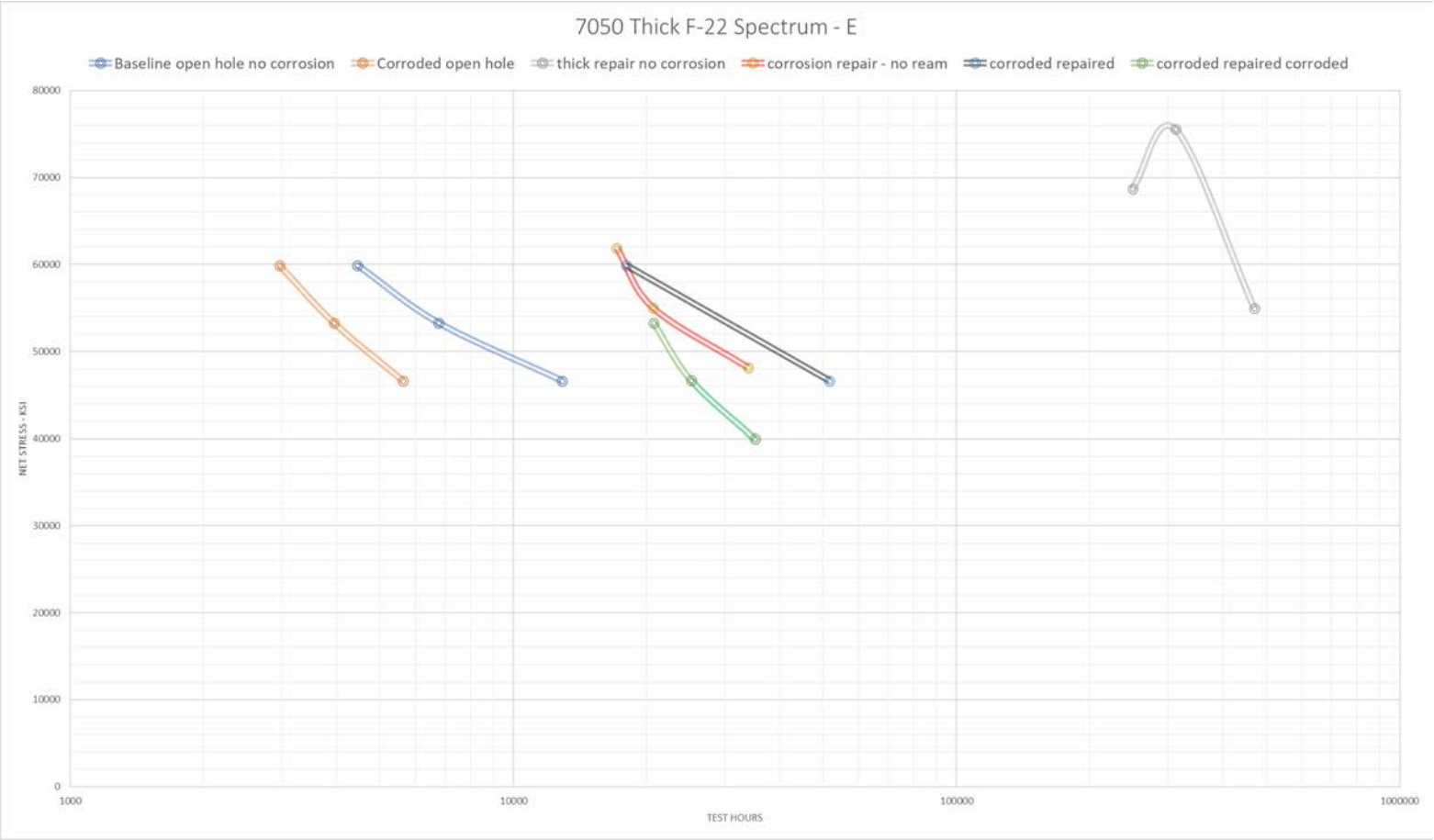


Baseline – open hole, no corrosion
Corroded - open hole
Repair - no corrosion
Corroded, reamed repaired
Corroded, reamed, repaired, corroded
Corroded, repaired (no ream)
Repaired when new, cycle for 10K cycles, then corrode and cut coupon in half to look for potential corrosion between bore of hole and barrel of thin wall bushing

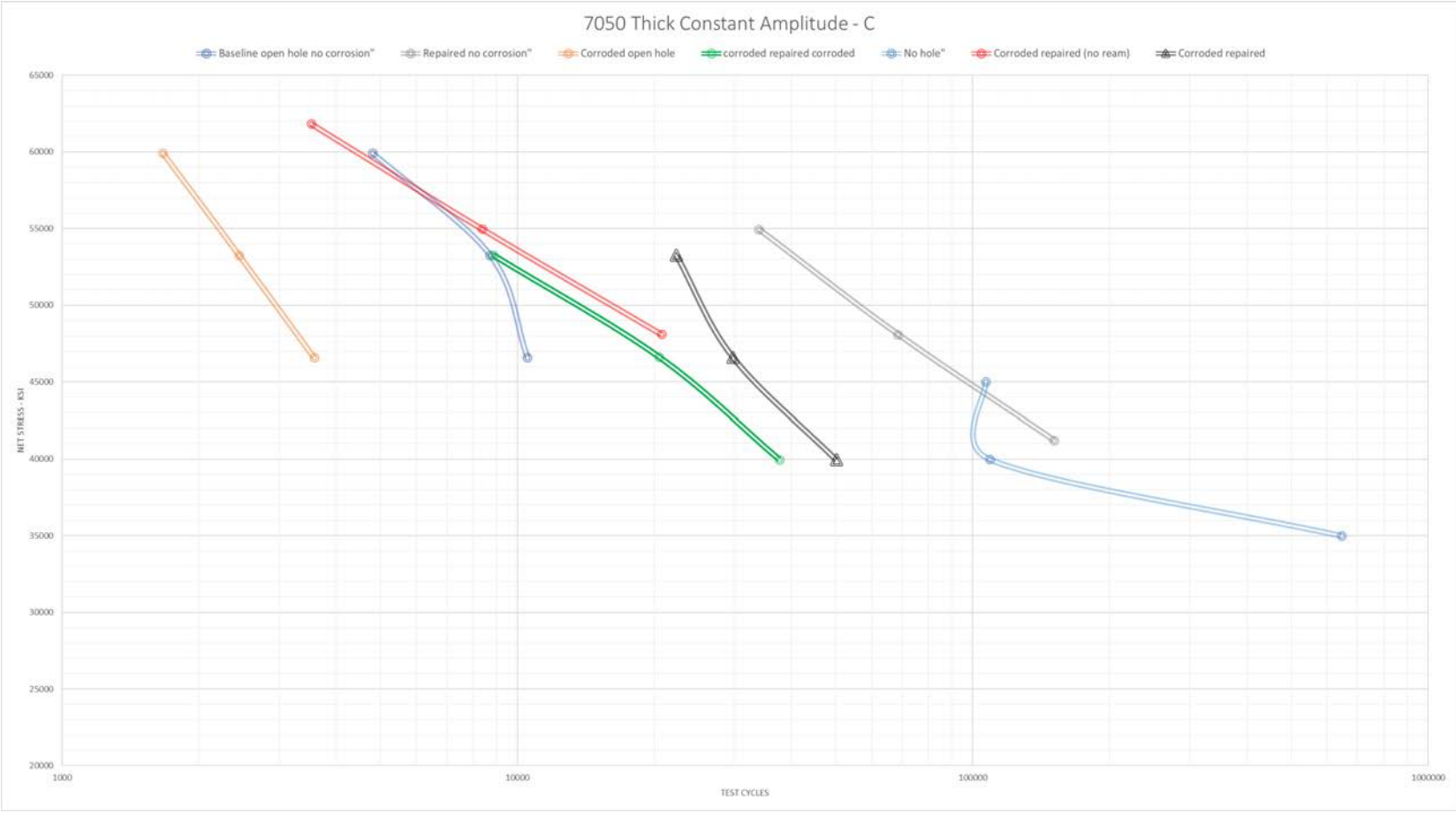
Fatigue Testing F-35 Spectrum



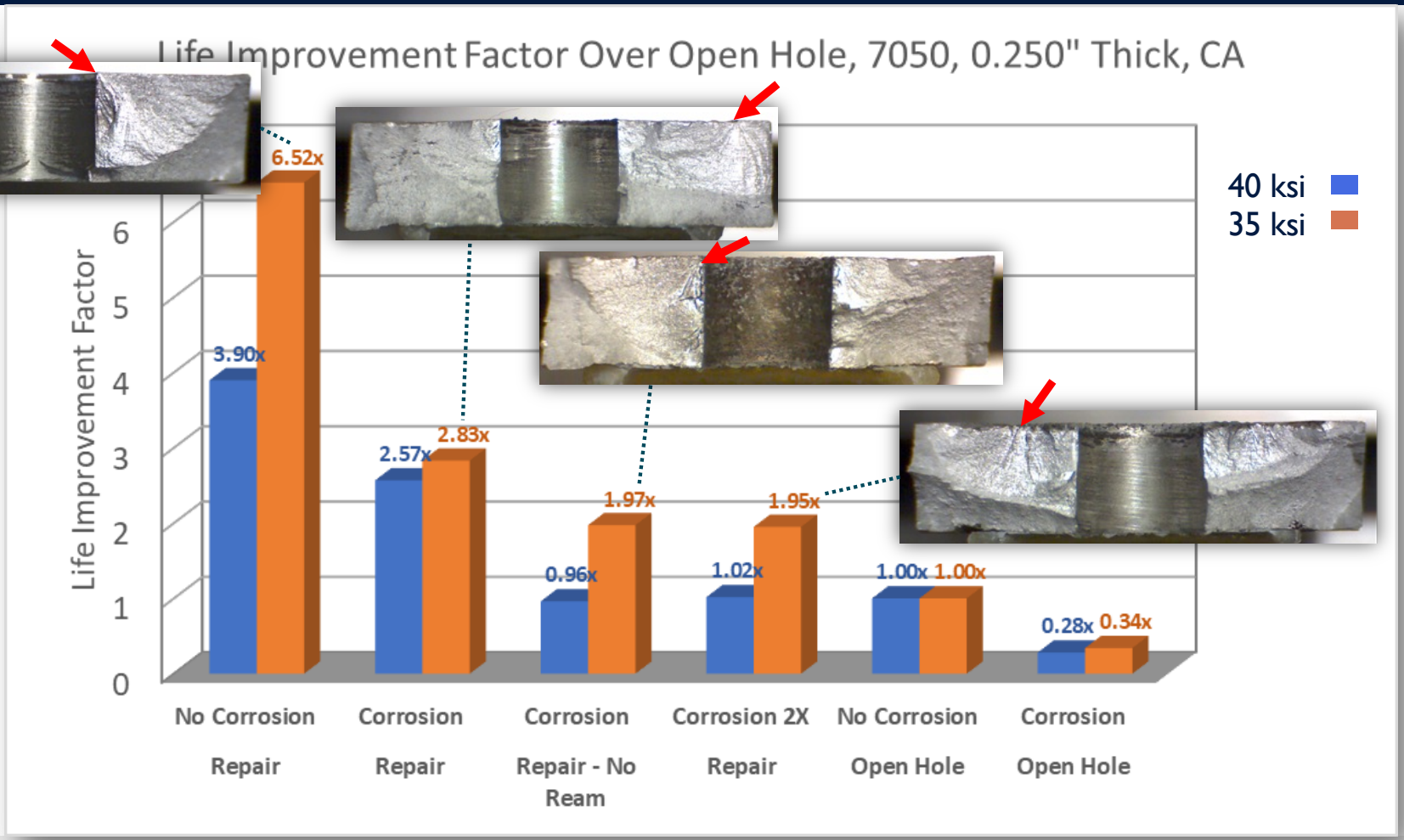
Fatigue Testing F-22 Spectrum



Fatigue Testing Constant Amplitude



Life Improvement Factor

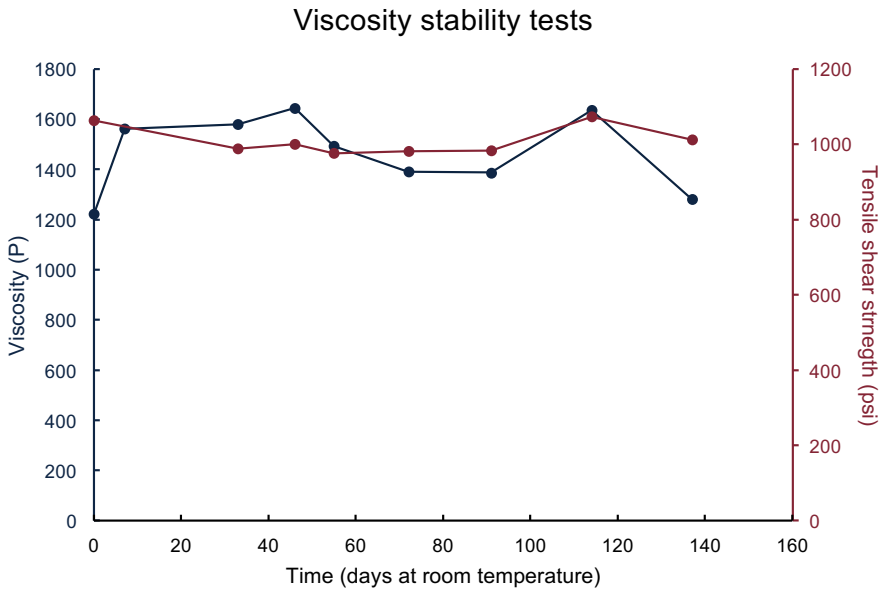


Adhesive Development

- Room Temp Stability prior to installation
- Chemical and Contamination Resistance
- Fuel and Water Resistance
- Temperature resistance

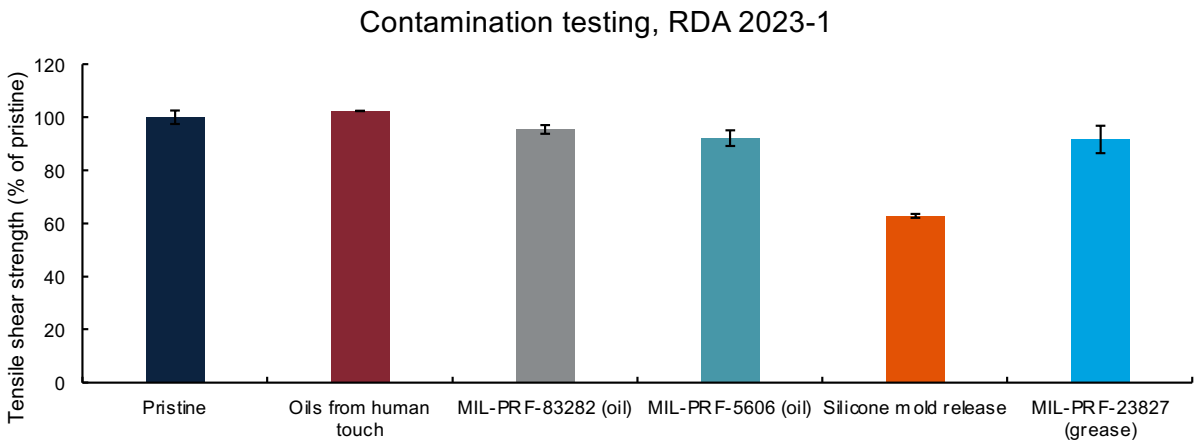
Adhesive - Stability at Room Temperature

23° C	30° C	40° C	Viscosity (P)	LSS (psi)
0 days	0 days	0 days	1222	1063 ± 34
7 days	4 days	2 days	1563	
33 days	20 days	10 days	1581	988 ± 60
46 days	28 days	14 days	1645	1000 ± 29
55 days	34 days	17 days	1493	976 ± 146
72 days	44 days	22 days	1392	982 ± 48
91 days	56 days	28 days	1387	984 ± 59
114 days	70 days	35 days	1635	1073 ± 68
137 days	84 days	42 days	1280	1013 ± 15



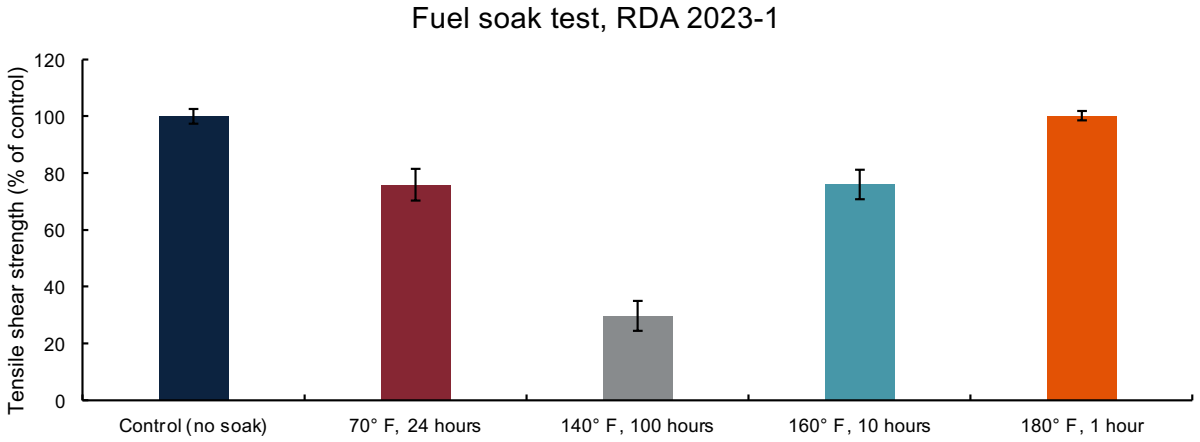
Adhesive - Chemical and Contamination Resistance

Batch	10006-61-A1	10006-61-A2	10006-61-A3	10006-61-A5	10006-61-A42	10006-64-A2
Formulation	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1
Contaminant	Pristine	Oils from human touch	MIL-PRF-83282 (oil)	MIL-PRF-5606 (oil)	Silicone mold release	MIL-PRF-23827 (grease)
LSS (psi)	1219 ± 31	1248 ± 1	1163 ± 20	1123 ± 36	766 ± 9	1117 ± 63
LSS (% of pristine)	100	102	95	92	63	92

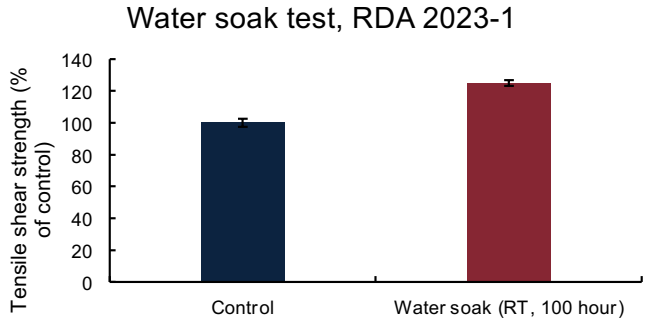


Adhesive – Fuel and Water Resistance

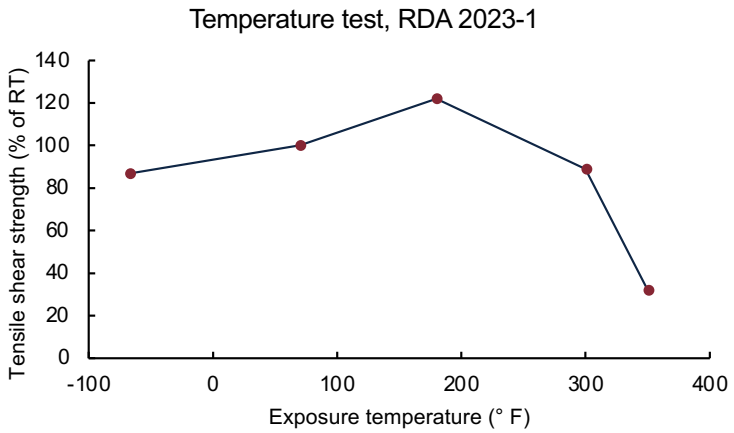
Batch	10006-63-A1	10006-63-A2	10006-63-A3	10006-63-A4	10006-63-A5
Formulation	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1
Exposure	Control (no soak)	70° F, 24 hours	140° F, 100 hours	160° F, 10 hours	180° F, 1 hour
LSS (psi)	1271 ± 33	965 ± 71	378 ± 67	966 ± 66	1274 ± 21
LSS (% of control)	100	76	30	76	100



	Control	Water soak (RT, 100 hour)
LSS (psi)	1219 ± 31	1523 ± 31
LSS (% of control)	100	125

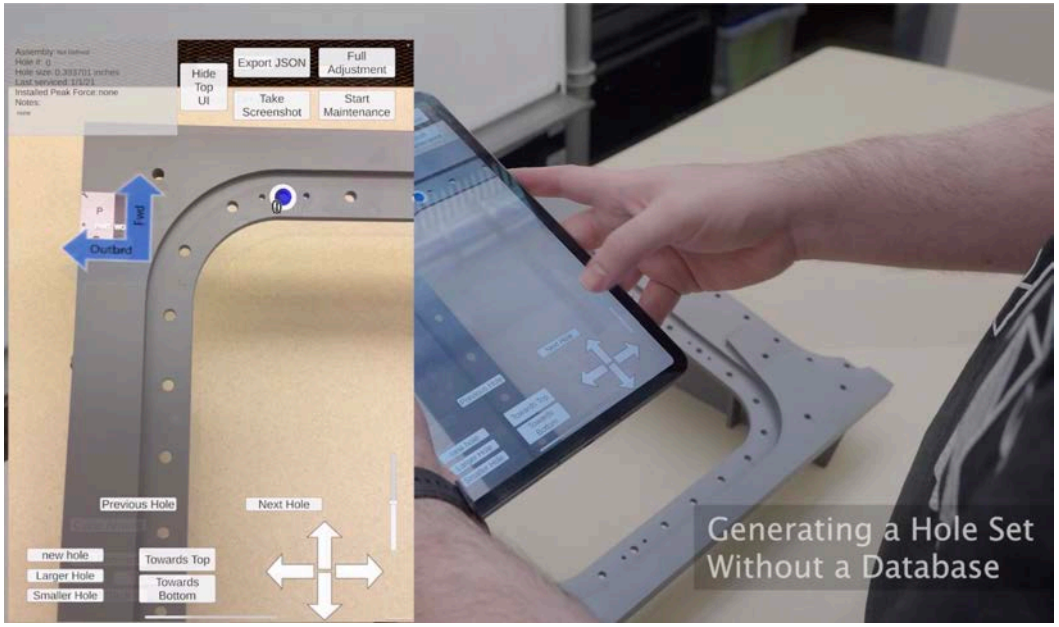


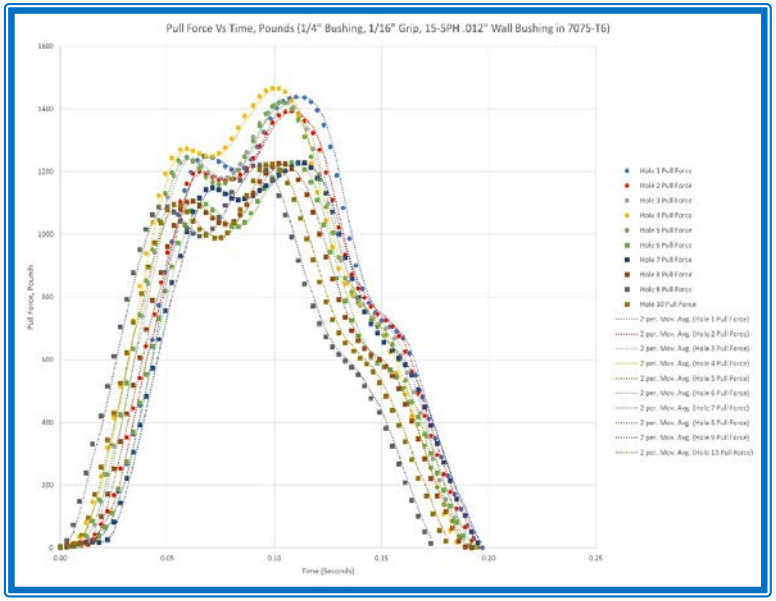
Temperature resistance



Batch	10006-62-A1	10006-61-A1	10006-62-A3	10006-62-A33	10006-62-A4
Formulation	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1	RDA 2023-1
Exposure	-67° F, 2 hours	Room temp	180° F, 2 hours	250° F, 2 hours	350° F, 2 hours
LSS (psi)	1058 ± 2	1219 ± 31	1492 ± 38	1080 ± 36	390 ± 47
LSS (% of RT)	87	100	122	89	32

Augmented Reality for Repair Tracking





- Record data real-time without operator intervention
- Validate correct hole repaired with right tooling/ fastener
- Simple set up with out complex calibration process
- Integrated scanning and mapping holes to database
- Compatible with phone/tablet/glasses/goggles

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 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

PART WORKS

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