PROTECTION ENGINEERING
PROTECTIVE COATINGS | PIPELINE PRODUCTS | COMPOSITES

Engineered Composite Solutions for Asset Integrity

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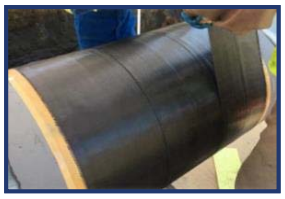
About Protection Engineering

WHO IS PROTECTION ENGINEERING?

- Leading supplier of permanent/temporary composite repair solutions for regulated and non-regulated pipelines.
- Leading supplier of liquid coatings, pipeline tape systems, epoxy pipeline coatings, shrink sleeves, waterproofing products, and CP products.
- Over 45 years in the business of structural coating systems, industrial coating systems, waterproofing products, and pipeline coating systems.



What are Composite Solutions?

- Solutions for safe and sustainable **construction, repair,** and **maintenance** of critical infrastructure.
- Products include Moisture Cured Fiberglass, Carbon Fiber/Epoxy, Rigid Coil E-glass, and Fiberglass/Epoxy Systems.
- These products are supported with best-in-class **design, engineering, testing,** and **training services**.
- Products are **easy to install, cost-effective to deploy,** and **durable for decades**.

PROTECTION ENGINEERING

PROTECTIVE COATINGS | PIPELINE PRODUCTS | COMPOSITES

Composites 101

Development, Engineering, Testing

WHAT IS A COMPOSITE?

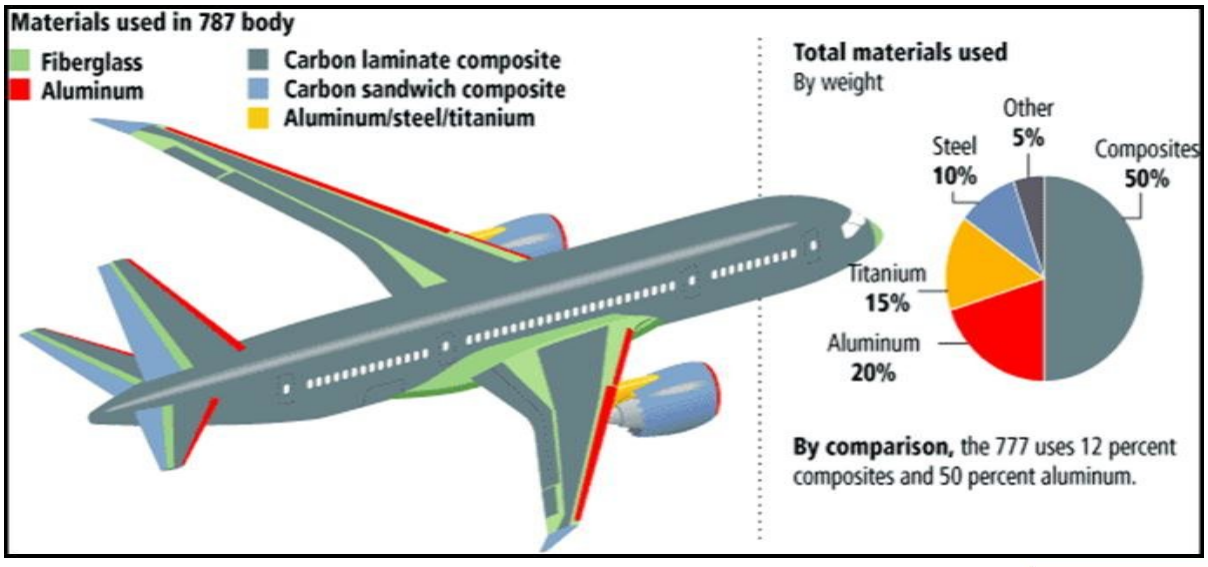
- Merriam-Webster Definition:
  - "Something made up of distinct parts"
- Examples:
  - Cement: Crushed limestone and clay
  - Reinforced concrete: concrete matrix, rebar reinforcement
  - Particle Board: wood chips, sawdust and binder

- In industry, composites refers to:
  - Matrix Phase
  - Reinforcing Phase

TECHNOLOGY ADOPTION

- Other industries that are rapidly adopting composites
  - Aerospace
  - Civil
  - Automotive
  - Leisure

TECHNOLOGY ADOPTION



TECHNOLOGY ADOPTION

- How far have composites come over the years?
- When rigid e-glass coils came out in the mid 1990's, handheld phones were huge

TECHNOLOGY ADOPTION

- When Water-Activated composites came out in the early 2000's, handheld phones were smaller and had more capabilities

TECHNOLOGY ADOPTION

- Carbon fiber composites have been around for 20+ years and are now tested, validated, and being used for crack reinforcement

WHY DO ASSET OWNERS/OPERATORS TRUST COMPOSITES FOR CRITICAL REPAIRS?

- **Robust engineering:** solutions designed to restore safety and prevent failure
- **Track record:** There are more and more successful repairs on infrastructure assets every year.
- **Testing/validation:** every composite solution we assist with has been rigorously tested in the lab and the field
- **Ease of use:** Composite solutions are easy to install, ensuring the highest quality repair each and every time

WHO TRUSTS COMPOSITES FOR PERMANENT REPAIRS?

KINDER MORGAN INC. · ENERGY TRANSFER · ENBRIDGE · TC Energy

PG&E · BOARDWALK PIPELINES · ATMOS energy · Williams · TALLGRASS

PLAINS · PHILLIPS 66 · nationalgrid · National Fuel · Southern Company

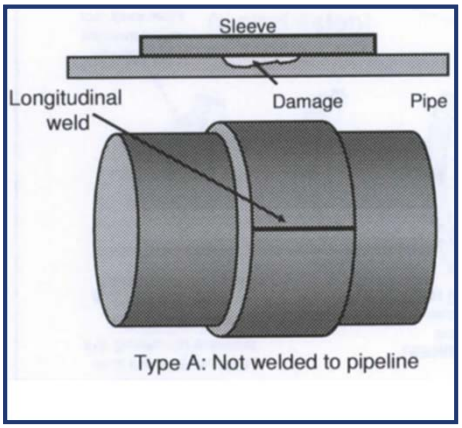
bp · ExxonMobil · NW Natural · SOUTHWEST GAS · dcp Midstream

And many more…

PROTECTION ENGINEERING

THINKING OUTSIDE THE BOX

- A composite is not the same as a Type A sleeve



PROTECTION ENGINEERING

COMPOSITE PIPE REPAIR

- Composite Repairs consist of:

- Thermoset Polymer Matrix
  - Protects the fibers
  - Holds repair together
  - Puts limits on temperature capabilities

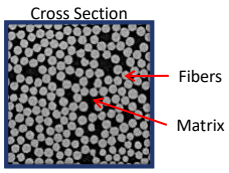
AND

- Fiber Reinforcement
  - Primary load carrying member
  - Directionally dependent

COMPOSITE SYSTEM

- Resin or 'Matrix' Contributions:
  - Environmental resistance
  - Chemical resistance
  - Temperature limit
  - Impact resistance
  - Abrasion resistance

- Fiber Contributions:
  - Directional strength
  - Binding for resin
  - Increased stiffness

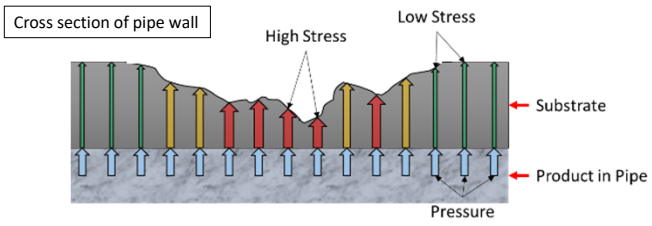


STYLES OF COMPOSITES

- Wet Lay-up
  - Resin and Fabric are sold separately
  - Best for on-site customization
  - Requires resin mixing
  - Ex: Carbon/Fiberglass
- Pre-impregnated
  - Resin and Fabric is shipped pre-mixed
  - Controlled resin / fiber ratio
  - Limited on-site customization
  - Ex: Water-Activated Wraps
- Pre-Cured
  - Resin is already set on the fabric
  - No on-site customization
  - Ex: Rigid Fiberglass

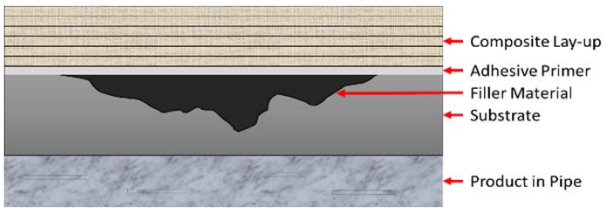
FUNDAMENTALS OF A COMPOSITE REPAIR

- Stress in corroded pipe
- Constant pressure through entire pipe wall causes stress in pipe
- Reduced wall thickness means increased stress
- If Stress is high enough, failure will occur



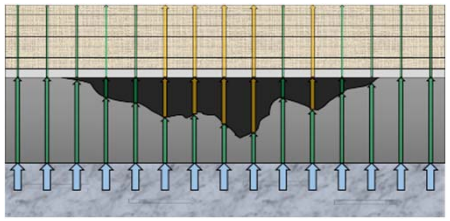
FUNDAMENTALS OF A COMPOSITE REPAIR

- Substrate (pipe) - Pipe needs to be cleaned and abraded
- Load Transfer Filler - Reshapes pipe and inhibits substrate yielding
- Adhesive Primer - Prevents water ingress, acts as coating
- Composite Lay-up - Provides structural rehabilitation



FUNDAMENTALS OF A COMPOSITE REPAIR

- Composite Strength Reinforcement
- Stress is distributed through the filler to the composite
- Stress absorbed by composite reduces strain in pipe
- Reduced strain means increased life



WHAT MAKES A REPAIR SYSTEM WORK?

Sound Science…
- Polymer Chemistry
- Fabric Architecture
- Composite Design
- Stress Distribution
- Metallurgy

… Proven Through Testing
- Component Level
- System Level
- Long-Term Testing
- Defect Specific Testing
- Third Party Certification

…and Designed Correctly
- Engineering Design and Review
- Documentation
- Follow ASME & ISO standards
- Custom designs as needed
- Conservative

PERMANENT PIPELINE REPAIR SOLUTIONS

PIPELINE SOLUTIONS OVERVIEW

- Composite Pipeline solutions are the industries:
  - High performing products
  - Highly tested products
- Composite repairs
  - Deliver fast, reliable and durable solutions
  - Withstand the test of time
  - Meet the required regulations

Addressable Defects

- External Corrosion
- Internal Wall Loss
- Dents
- Gouges
- Crack-like features
- Wrinkle Bends
- Manufacturing Defects

Follows, as applicable:

- US CFR Title 49 Part 192 & 195
- ASME B31.8
- ASME B31.4
- ASME PCC-2
- CSA Z662
- ISO 24817
- and many more local requirements

PIPELINE VALUE CREATION

- Composite solutions provide the following cost saving opportunities:
  - Quicker time to backfill
  - Installation while the pipeline is in service
  - Shorter repair length due to no landing zone restrictions
  - Less wait time to perform NDE
- Average cost savings per dig can be upwards of 50% compared to steel sleeves
  - Example: 8" OD, 3 ft repair length
    - Steel Sleeve = $22k: 3 days, welders, NDE technicians, materials
    - Composite = $11k: 1-day, quick install and curing, immediate coating and backfill, materials

APPROVALS AND REGULATORY COMPLIANCE

- United States DOT CFR 192 and 195
  - CFR 192.713, 195.585: "repair the pipe by a method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe"
- CSA Z662 – complies with code and is considered a "permanent repair"
  - Reference Clause 10.11.4.3 and Table 10.2 for specifics
- ASME B31.1, B31.3, B31.4, and B31.8 allow for composite repairs
- ASME PCC-2 Article 401 and ISO/TS 24817
  - Meets all required testing and provides basic design methodology
- Det Norske Veritas (DNV), ABS and Lloyd's Register Type Approval

RELIABLE ENGINEERING TESTING: 3RD PARTY VALIDATED

- PRCI:
  - MATR-3-4: Long-term Performance (10-year)
  - MATR-3-5: Dented Weld Seam
  - MATR-3-7: Vintage Girth Weld Reinforcement
  - MATR-3-11: Load Transfer Study
  - MATR-3-13: Repair of Dents Installing at Pressure
- JIP's:
  - GRI – 10-year study
  - GTI – long term adhesive and cathodic disbondment testing
  - Wrinkle Bend Reinforcement
  - The Reinforcement of Non-Leaking Crack-Like Defects using Composite Repair Materials
  - 10,000hr Offshore Test
  - Dent Validation (DVCIP)
  - Selective Seam Weld Corrosion (SSWC)
  - Stress Corrosion Cracking (SCC)
  - Girth Weld Geohazard Reinforcement JIP
  - Many more

CORROSION – PRCI MATR-3-4: LONG-TERM 10-YEAR BURIED STUDY

- 40%, 60%, and 75% machined wall loss
- Installed same repair thickness on all specimens with same wall loss regardless of repair design life
- Subjected to 900 pressure cycles per year and then burst a test specimen every year for 10 years

CORROSION – PRCI MATR-3-4: LONG-TERM 10-YEAR BURIED STUDY

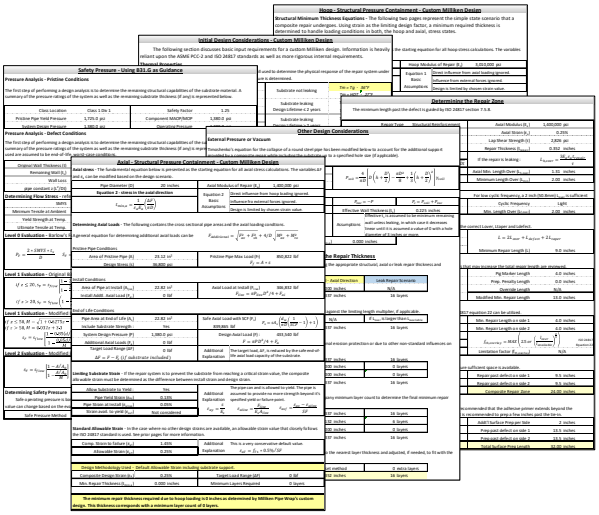
- All burst pressures were within 100 psi of the average
- All burst pressures were within a standard deviation of 65 psi of each other
- Shows that Carbon Fiber / Epoxy systems maintain strength over time

Burst Pressures by Year

Wall Loss	Year 0	Year 1	Year 2	Year 3	Year 5	Year 7.5	Year 10
40%	4,125 psi	4,040 psi	4,087 psi	4,123 psi	4,188 psi	4,117 psi	4,247 psi
60%	4,118 psi	4,089 psi	4,084 psi	4,191 psi	4,241 psi	4,089 psi	4,122 psi
75%	4,296 psi	4,263 psi	4,388 psi	4,397 psi	4,316 psi	4,328 psi	4,322 psi

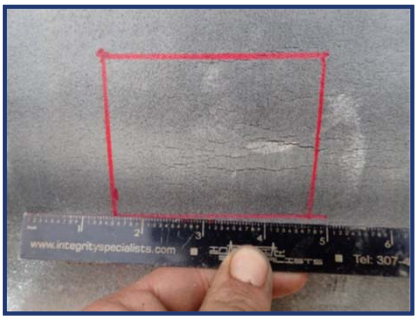
RELIABLE ENGINEERING ANALYSIS: IN-DEPTH DOCUMENTATION FROM START TO FINISH

- Repair Questionnaire
- Design Package
- Job Package
  - Repair Summary
  - Defect Verification
  - Quality Verification Form
- Field Installation Report



ENGINEERING DESIGN

- Corrosion
  - Barlow's, B31G, RSTRENG, etc.
- Dents
  - Including with interacting defects
- Wrinkles
- Manufacturing defects
- Cracks/fracture mechanics
- Cyclic fatigue
- Axial loading
- Bending loading
- Geohazard loading
- ECA's for additional anomalies



TRAINING

- **ASME PCC-2 mandates that all installers must be certified, using AT LEAST the following parameters:**
  1. Classroom training to cover basic repair concepts, composite theory and common mistakes to avoid
  2. Hands on training, in which each participant will partake in a minimum of 2 installations
  3. Must pass a certification exam with a score of 80% or higher
- **After initial certification, installers may recertify for the next 2 years via an online program or retaking the exam**
- **Every 3rd year they must go through the full training course again**

"Practice does not make perfect.
Only perfect practice makes perfect."
- Vince Lombardi

Permanent Pipeline Repair Products

Pre-Impregnated Water Activated Wrap

Carbon Fiber/Epoxy Resin Wrap

PRE-PREG WATER ACTIVATED

- The system
  - Utilizes a standard filler and primer
  - High-strength, bi-directional fiberglass
  - Pre-impregnated polyurethane resin
- Water activated system
  - Only need water to install and cure
  - Applies wet, can conform to geometry
- Best suited for low severity defects
  - Corrosion, gouges, and small dents
  - Works on elbows and bends

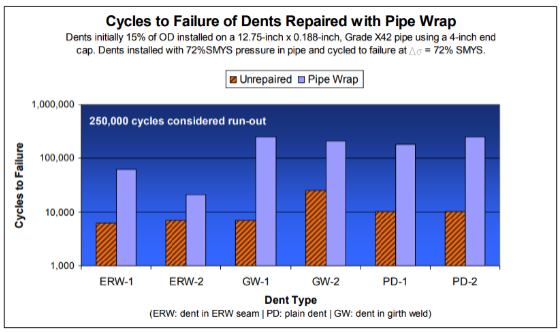
PRCI MATR-3-4 3-YEAR CORROSION BURIED STUDY

- 12”, X42, 0.375” original WT
- 40%, 60%, and 75% machined wall loss
- Subjected to 900 pressure cycles at ΔP = 36% SMYS per year and then burst a test specimen every year for 10 years
- Survived cyclic fatigue, burst outside the defected area in base pipe

Wall Loss	Year 0	Year 1	Year 2	Year 3
40%	4,182 psi	4,161 psi	4,250 psi	4,189 psi
60%	4,100 psi	4,203 psi	4,327 psi	4,233 psi
75%	4,211 psi	4,168 psi	4,265 psi	4,285 psi

PRCI MATR-3-5 DENT REPAIR STUDY

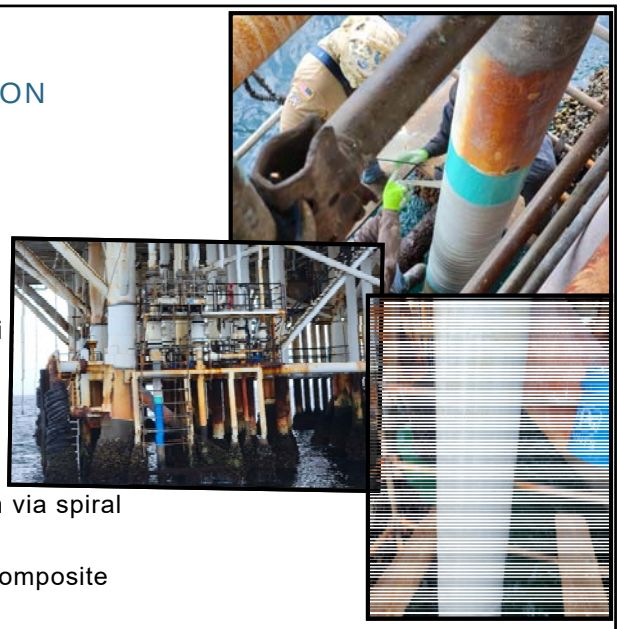
- 12”, X42, 0.375” original WT
- Dent on pipe body, ERW seam weld, and girth weld
- Subjected to 250,000 pressure cycles at ΔP = 72% SMYS or failure



INSTALLATION STEPS

PRE-PREG WRAP – EXTERNAL CORROSION

- Location:
  - Southern California
- Pipe Details:
  - 12” OD, X52, 0.5” Wall, Crude Oil Pipeline
  - 1036psi MAOP, Operating pressure = 600psi
- Defect Information:
  - 0.36 Wall Loss – External Corrosion
- Application:
  - 16-layer system was installed over 5’ section via spiral wrap in about 2 hours.
  - Line was kept in service during install, and composite repair installation avoided a costly shutdown



CARBON/EPOXY SYSTEM

- The system: carbon fiber and epoxy
  - Utilizes a load transfer filler and epoxy coating
  - High-strength, bi-directional carbon fiber
  - 2-part epoxy wet-out system, pre-measured
- Field saturated wet lay-up
  - Can be applied to unique geometries
  - Provides best close-fit to the pipe
- Best suited for high severity defects
  - Large dents, wrinkle bends, and weld defects
  - Crack and crack-like features
  - Great for lines with heavy cycling

CARBON/EPOXY VARIANTS



- Standard
  - Bi-directional carbon fiber
  - Ambient cure epoxy
  - Engineered for hoop stresses
- High Temperature
  - Bi-directional carbon fiber
  - High-temp epoxy (450°F)
  - Engineered for hoop stresses
- UA (HT)
  - Uni-directional carbon (axial)
  - Ambient or HT cure epoxy
  - Engineered for axial stresses

CARBON COMPOSITE – INSTALLATION

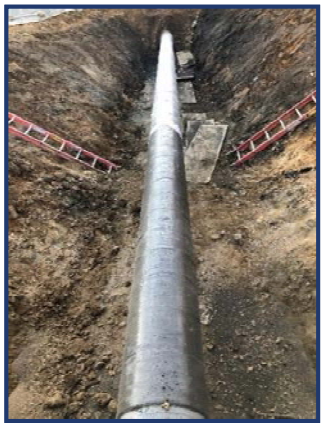
CARBON COMPOSITE – SEAM WELD CRACKS

- Location
  - Louisiana
- Overview
  - Pipe Diameter: 16”
  - Design Pressure: 1336 psi MAOP
  - Pipe Contents: Ethylene
  - Pipe Defect: 33% deep by 3” crack-like defect in the seam weld
- Solution
  - Atlas engineered for 3’ repair length
  - Based on test program
  - Type B welded sleeve was not feasible as it would have caused an explosion
  - Avoided down time, kept line in service, and restored pipe to beyond original strength

CARBON COMPOSITE – WRINKLE BEND

- Location:
  - Louisiana
- Overview:
  - 3 Wrinkles with External Corrosion on a 26”OD Natural Gas Pipeline
  - 0.281” WT, X52, 840psi MAOP, Class 1
  - Wrinkles: 0.75” high, 4” wide, 3:30-8:30 position
  - Ext. Corrosion: 15” long, 19” wide, 0.59” max depth
- Solution:
  - Engineered design called for carbon composite over an 89 linear inch repair zone
  - Repair intended to have a 20-year design life
  - Applied in 2 hours and 20 minutes by certified installers
  - Restored strength and prevents failure due to bending fatigue

CARBON COMPOSITE – HARD SPOTS



- Location
  - Pennsylvania
- Overview
  - Pipe Diameter: 20”
  - Design Pressure: 1134 psi MAOP
  - Pipe Contents: Natural Gas
  - Pipe Defect: Hard spots, brittle seam weld, Brinell Hardness >300
- Solution
  - Atlas engineered for 53’ repair length
  - Type B welded sleeve was not feasible due to length and down time required
  - Avoided down time, kept line in service, and restored pipe to beyond original strength

CARBON COMPOSITE – VINTAGE GIRTH WELDS

- Location
  - Europe
- Overview
  - 20” and 24” Crude Oil Pipelines, 435 psi design
  - Reinforce vintage (Soviet era) girth welds
    - Manufacturing Defects
    - Lack of fusion
- Solution
  - Validated with FEA and full-scale spools
  - Reinforced over 1500 welds
  - Kept line in service during rehabilitation
  - Saved millions of dollars compared to alternative repairs

CARBON COMPOSITE – INTERNAL CORROSION

- Location:
  - Texas
- Overview:
  - 26” OD, X65, .406” wall, crude oil pipeline
  - 1440psi MAOP, Operating pressure = 350psi
  - Design pressure: 1465 psi
  - Internal corrosion designed to 80% wall loss over (1) 6ft span and (1) 8ft span.
- Solution:
  - Both spans completed in 2 days utilizing engineered carbon fiber repair.
  - Pipeline operator was able to extend the life of the pipeline and will be able to clearly monitor this area of corrosion with ILI tools without any interference of the repair.

NEW(ISH) APPLICATION - COMPOSITE REPAIRS ON CRACKS

- 2015 – Testing on pipe with seam weld cracks using the carbon composite repair system – Operator: Boardwalk
  - Test showed that composite repairs can reinforce a cracked seam weld
  - Tested 3-inch-long cracks at 33% and 75% depth
- 2016 – JIP test program on similar cracks with a focus on cyclic fatigue
  - Test showed that composite repairs can significantly increase remaining crack life
  - Tested 3-inch-long cracks at 15% and 50% depth
- 2017-2021 - various owner / operator private testing
  - Shows continued success under various conditions
  - Includes testing with ExxonMobil, Williams, and more
  - JIP (2021 with ADV) – ongoing

SUMMARY OF BURST TESTING

- Diameters tested: 8, 12, 16, 22, 36 inches
- Wall thicknesses: 0.219, 0.250, 0.312, 0.406 inches
- Crack lengths: 0.6 – 10.2 inches
- Crack depths: 33% ~ 75%
- Fracture toughness range: 32,000 – 321,000 psi-in$^{0.5}$

- Over 50 crack or crack-like features burst
  - All reasonable scenarios had failure initiate outside of the composite repair zone
  - Exceptions: very low layer counts in severe defects (intentional failure in repair)

- Conclusion:
  - In short term burst scenarios, a properly designed composite prevents rapid crack growth initiation

SUMMARY OF CYCLIC TESTING

- Diameters tested: 8, 12, 16, 22, 30 inches
- Wall thicknesses: 0.219, 0.250, 0.312 inches
- Crack lengths: 1.5 – 3 inches
- Crack depths: 15% ~ 57%
- Fracture toughness range: 32,000 – 321,000 psi-in0.5

- Over 60 cracks cycled to failure
  - Measured cycles to failure compared to un-reinforced 2-125 times longer
  - The more severe the initial crack, the more dramatic the impact

- Conclusion:
  - In cyclic fatigue scenarios, a properly designed composite repair can drastically reduce crack propagation rate

RECAP BENEFITS OF USING COMPOSITE REPAIRS

- Easy to install
  - Leads to higher reliability of repair performance in the field, quicker installation
  - Liquid epoxy primer coating – prevents moisture ingress
  - Thinner fabric is easier to saturate and install with less sagging and install defects
- Engineering supported field designs with rapid turn around time
- New product developments have brought down cost per repair
- Continuously testing and improving the product capabilities and engineering support
- Materials engineered to be able to install, topcoat and backfill same day, allowing ditch to close quicker
- Compatible with CP Systems

PRESENTATIONS SHOULD ALWAYS END WITH A BANG!

QUESTIONS?