# Internal Repair of Pipelines – Project Review Meeting

## NETL Project No. NT 41633

May 12, 2005 – Morgantown, WV


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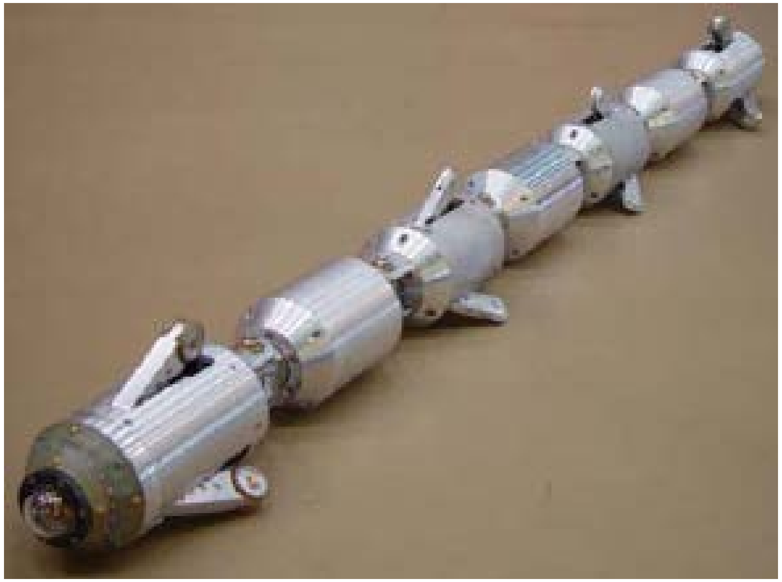
# Introduction – 1

- External, corrosion-caused loss of wall thickness is the most common cause of repair for gas transmission pipelines
- As pipelines become older, more repairs are required
- Internal (i.e., trenchless) repair methods are an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded
  - Particularly true for pipelines in environmentally sensitive and highly populated areas

# Introduction – 2

- A successfully-developed internal repair method could be coupled to an autonomous internal inspection robot (e.g., EXPLORER II)
  - Provide continuous inspection AND repair capability for natural gas infrastructure



# Background – 1

- To prevent an area of corrosion damage from causing a pipeline to rupture, the area containing the corrosion damage must be reinforced
- The most common method for repair of gas transmission pipelines to install a welded full-encirclement steel repair sleeve
  - Resist hoop stress
  - Can resist axial stresses if ends are welded

# Background – 2

- Several existing external repair methods are, in theory, directly applicable from the inside
  - Further development needs:
    - Equipment to perform repairs remotely
    - Mobilization of equipment through the pipeline to areas that require repair
- Several repair methods commonly applied to other types of pipelines (gas distribution lines, water lines, etc.) also have potential
  - Many of these require further development to meet the requirements for structural repair of gas transmission pipelines

# NETL Program/Objectives

- DOE National Energy Technology Laboratory (NETL) program to develop internal repair technology for gas transmission pipelines
  - Edison Welding Institute (EWI), Pacific Gas & Electric Company (PG&E), and Pipeline Research Council International, Inc. (PRCI).
- Evaluate, develop, and validate internal repair methods for pipelines
- Perform a laboratory demonstration of internal pipeline repair
- Develop a functional specification for a prototype system

# Presentation Outline

- Review and assessment of candidate repair methods
- Survey of operator experience & industry needs
- Evaluation of potential repair methods
- Development of candidate repair methods
- Optimization of fiber-reinforced composite repair
- Evaluation of NDE methods
- Demonstration format
- Review of project plan/planned activities
- Summary and conclusions

# Review and Assessment of Candidate Repair Methods

- Two broad categories of repair that are potentially applicable to gas transmission pipelines from the inside were identified
- Weld deposition
  - Direct
  - Relatively inexpensive to apply
  - Requires no additional materials beyond welding consumables
- Fiber-reinforced composite liners
  - Primary advantage is that the need for welding is precluded

# Weld Deposition Repair

- Proven technology
  - Can be applied directly to the area of wall loss (e.g., external repair of external wall loss)
  - Can be applied to the side opposite the wall loss (e.g., external repair of internal wall loss)
- No apparent technical limitations to the application to the inside of an out-of-service pipeline (e.g., internal repair of external wall loss)
  - Application to the inside of an in-service pipeline may require that the methane gas be excluded from welding environment

# Robotic Weld Repair Systems – 1

- Developed primarily by needs in the nuclear power industry
- Working devices have been built for other applications
  - Osaka Gas
    - Remote robotic equipment for repair of flaws in the root area of girth welds in gas transmission lines
  - PG&E Internal Pipeline NDE System (IPNS)
    - Uses several inspection technologies to characterize girth weld and long seam flaws, corrosion, and dents and gouges
    - Grinder is incorporated for preparation of areas of interest

# Robotic Weld Repair Systems – 2


Osaka Gas

WISOR


# Development Needs for Weld Deposition Repair

- System capabilities include:
  - Ability to operate at long range from the pipe entry point (i.e., 2,000+ ft)
  - Ability to traverse bends and miters
  - Machining capability to prepare the area
  - Grinding system for cleaning and preparation
  - High deposition, robust welding process
- Many of these features are incorporated in existing systems
- No single system possesses all required characteristics

# Fiber-Reinforced Composite Repair – 1

- Becoming widely used as an alternative to the installation of welded full-encirclement steel sleeves for repair of gas transmission pipelines
  - Glass fibers in a polymer matrix material bonded to the pipe using an adhesive
  - Existing repair devices (e.g., ClockSpring®) are not directly applicable to internal repair

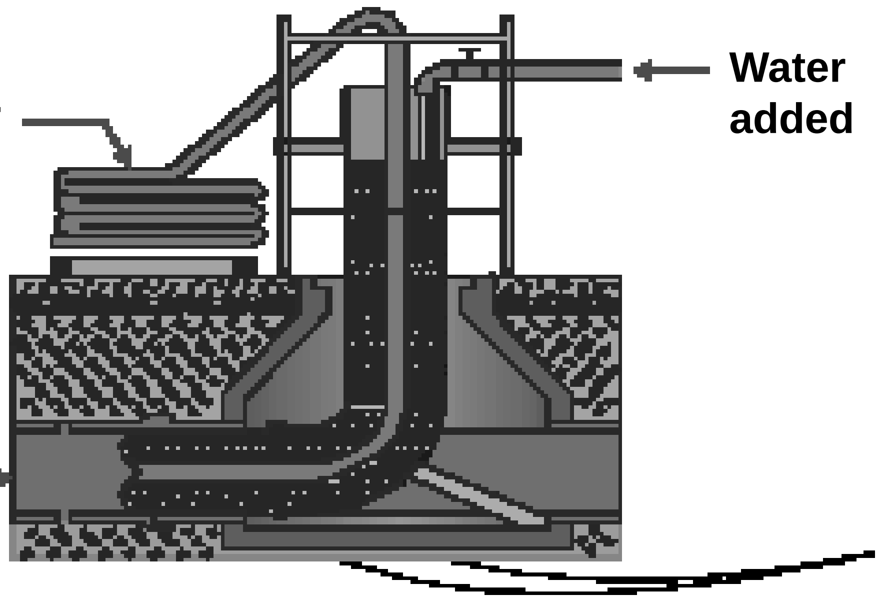
- Composite-reinforced line pipe (CRLP) being considered for new construction

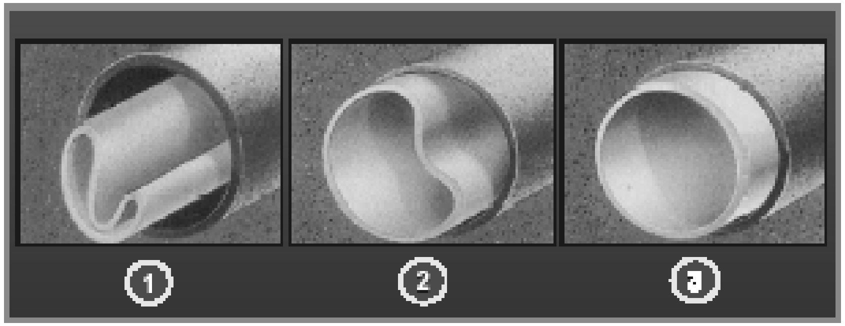
# Fiber-Reinforced Composite Repair – 2

- Liners are commonly used for repair and rehabilitation of other types of pipelines (gas distribution lines, sewers, water mains, etc.)
  - Sectional liners
  - Cured-in-place liners
  - Fold-and-formed liners
- Primarily used to restore leak-tightness
- Most are not considered structural repairs

# Liner Installation Processes – 1

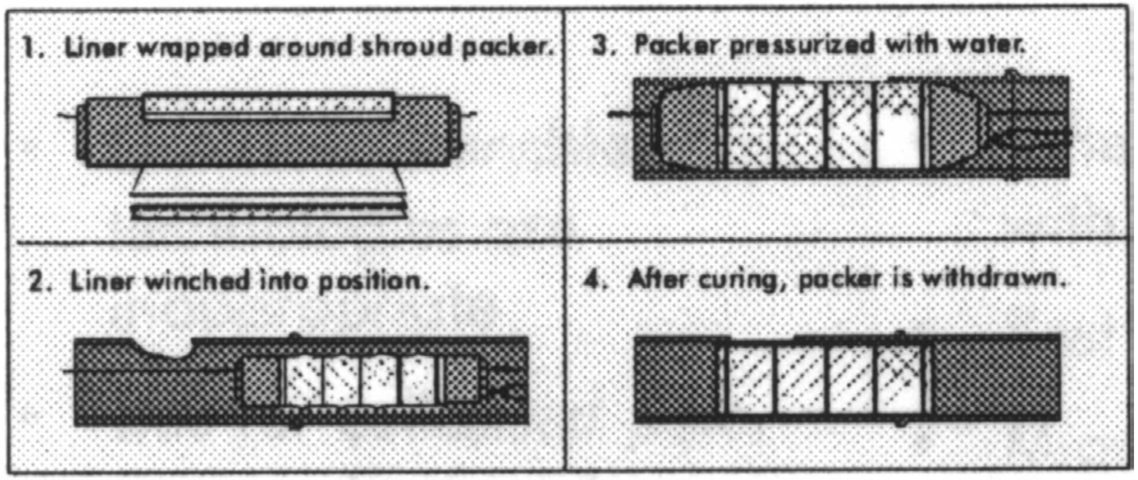
Cured-in-place (inversion process)

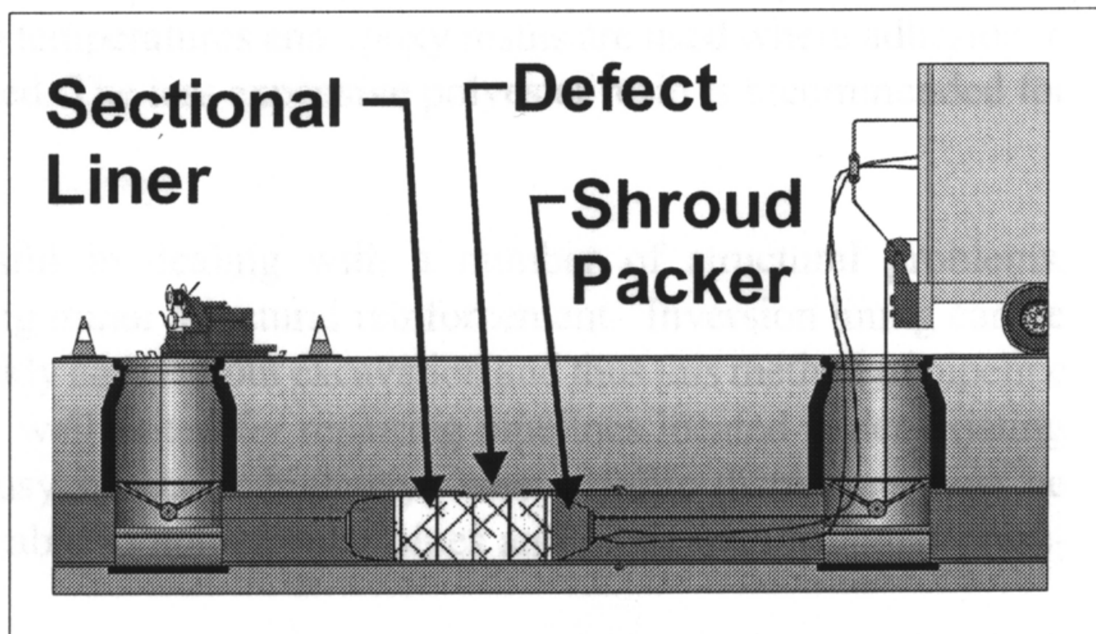



Fold-and-formed

# Liner Installation Processes – 2



# Development Needs for Composite Repair

- Development of composite repair/liner materials with sufficient strength and stiffness for structural repair
- Adhesion of the liner to the pipe surface
- Required thickness for structural reinforcement
  - Potentially adverse effect on internal inspection and flow restriction

- Combine strength of external repair products with installation process currently used for liners

# Survey of Operator Experience & Industry Needs

- Better understand the needs and performance requirements of the industry regarding internal repair
- Six parts
  - Currently used repair methods
  - Use/potential use of internal repair
  - Need for in-service internal repair
  - Applicable types of damage
  - Operational and performance requirements
  - General comments

## Survey Results – 1

- 56 surveys were sent out to gas transmission pipeline companies
- 20 completed surveys were returned
  - 36% response rate
- Most common type of currently-used repair
  - Welded full-encirclement steel repair sleeves
- Other currently used repair methods
  - "Cut out and replace"
  - Fiber-reinforced composite wrap repairs (e.g., ClockSpring®)
  - Grind-out repairs

# Survey Results – 2

- One company reported experience with internal repair of a gas transmission line
  - Plastic tight liners and plastic slip liners for lower pressure lines (less than 100 psi)
- Nearly all of the companies responded that, if internal repair was to become a proven technology, they would use it
  - Most attractive for applications where conventional excavated repairs are difficult
    - River crossings, under other bodies of water (e.g., lakes and swamps), in difficult soil conditions, under highways or congested intersections, and under railway crossings

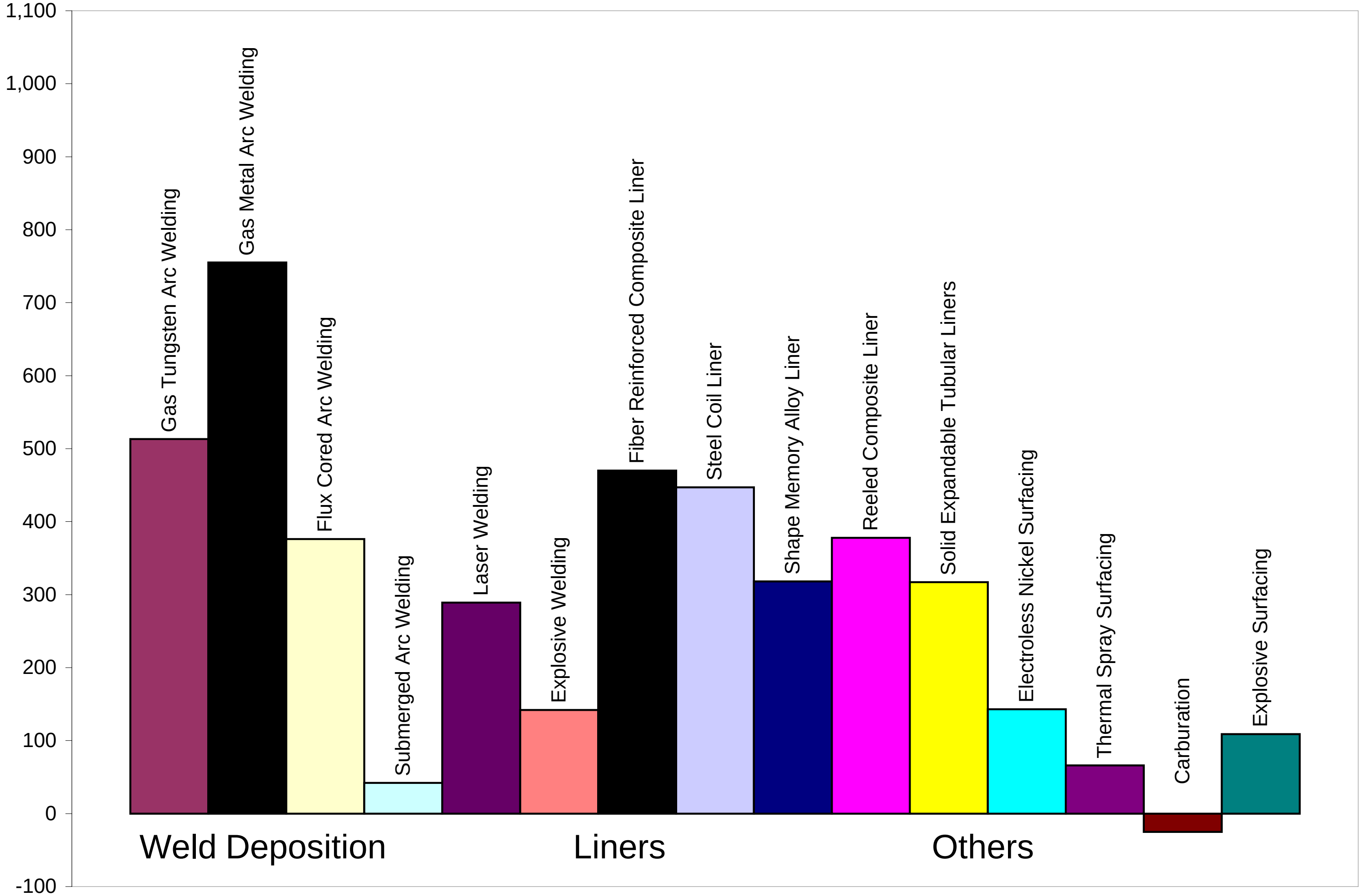
# Survey Results – 3

- Typical travel distances required for an internal repair system
  - Up to 1,000 ft
  - Between 1,000 and 2,000 ft
    - Despooled umbilical systems
  - Beyond 3,000 ft
    - Self-propelled system with onboard self-contained power system
- Pipe diameter requirements
  - Range from 2 to 48 in. diameter
  - Most common size range is 20 to 30 in. diameter

# Evaluation of Potential Repair Methods

- Evaluation exercise was carried out to determine which specific repair options should be emphasized in the experimental portion of this project
- Five major feasibility categories were included
  - Technical feasibility
  - Inspectability of completed repairs
  - Technical feasibility of the process while the pipeline is in service
  - Repair cost
  - Industry experience with the repair method

# Composite Score for Potential Repair Methods



# Development of Candidate Repair Methods

- Fiber-reinforced composite liner repair
  - Development of fiber-reinforced liners with the appropriate strength and stiffness
- Weld deposition repair
  - Evaluation of various commercially available systems for internal weld deposition using gas-metal arc welding (GMAW)
  - Development of baseline welding parameters

# Fiber-Reinforced Composite Repair

- Initial test program focused on a modified version of existing product manufactured by RolaTube
  - Bi-stable reeled composite material used to make strong, lightweight, composite pipe
- Upon being unreeled, changes shape from flat strip to overlapping circular pipe/liner that can be pulled into position
- Longitudinally seam welded following deployment
- Adhesive activated and cured using induction heating

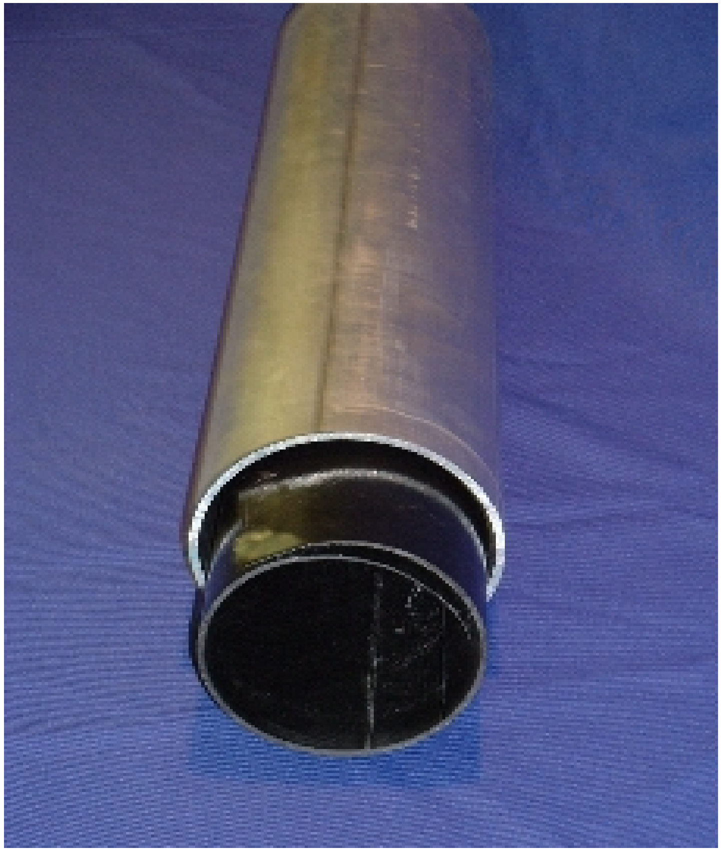
# Liner Material Lay-up and Forming

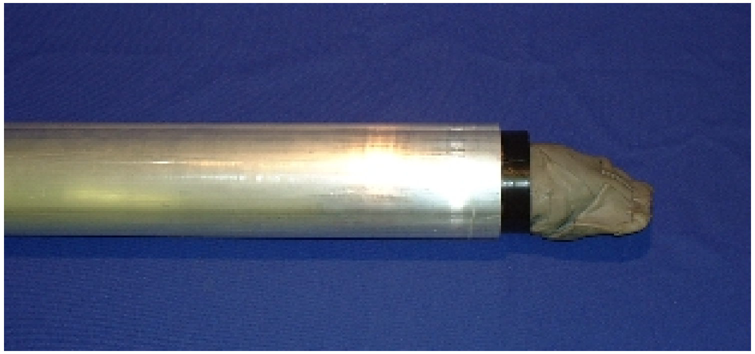
- Lay-up
  - 9 plies of glass-polypropylene precursor (Plytron)
    - "Pre-preg" tapes of unidirectional glass and polymer
    - +/- 45º orientation
  - Tapered overlapping seam
- Forming
  - Plies consolidated into liner with heat and pressure
  - Wall thickness of liner is 0.11 in.

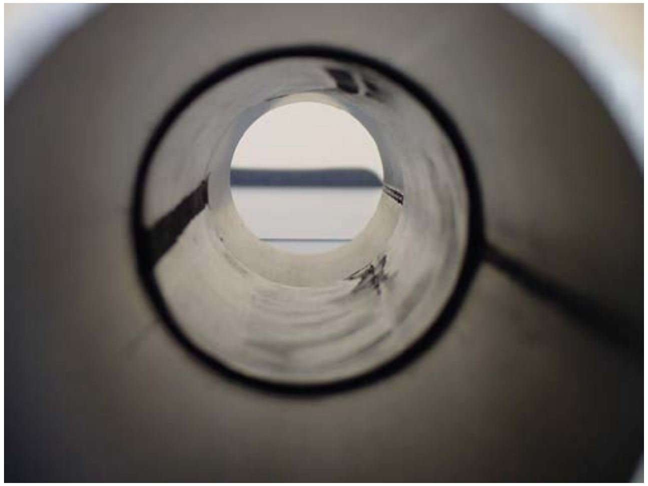
# Pipe Lining Process

- API 5L Grade B – 4.5 in. diameter by 0.156 in. wall thickness
- Procedure
  - De-grease and prepare inner surface
  - Insert silicon rubber bag into liner and locate inside pipe
  - Inflate bag to press liner against pipe wall
  - Heat to ~400º F in oven to fuse liner to pipe wall
- Test set up required external heating of pipe
  - In field, possible choices include:
    - IR heaters on an expansion pig
    - Inflatable bag using hot air

# Pipe Lining Process







# Simulated Corrosion Damage

- Simulated corrosion damage was introduced into four pipe sections
  - Two without lining and two with lining
- Long, shallow damage representative of general corrosion
- Short, deep damage representative of a deep isolated corrosion pit
  - ~30% reduction in burst pressure

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# Hydrostatic Pressure Testing

- Failure pressures for pipes with liners were only marginally greater than pipes without liners
- Analysis of results
  - Difference in modulus of elasticity between the steel and the liner material prevents the liner from carrying its share of the load
- Disbonding was not an issue


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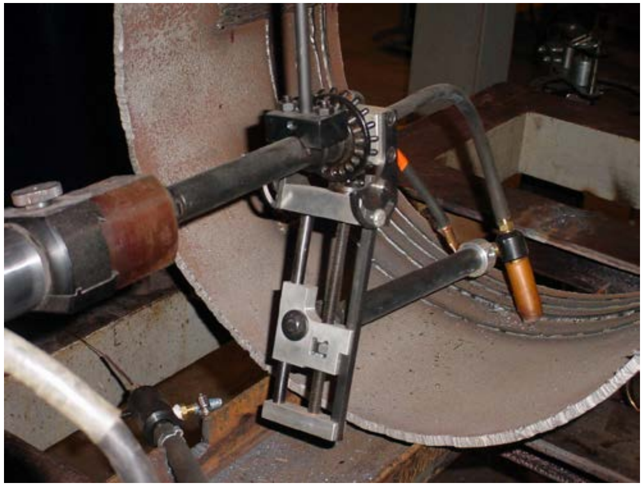
# Development Needs for Fiber-Reinforced Composite Repair

- Liner materials with a modulus of elasticity closer to that of steel is required
  - Steel ~ 30 x $10^6$ psi
  - Glass-polypropylene material ~ 2.2 x $10^6$ psi
  - Carbon-based composite material ~ 10 to 26 x $10^6$ psi
- Finite element analysis to determine required liner material properties and thickness
- Repeat experiments using liner material with suitable properties
  - Pipe diameter representative of typical gas transmission pipeline

# Weld Deposition Repair

- Three welding systems were evaluated for use in the development of welding parameters
  - Internal bore cladding system (Bortech)
  - Six-axis robot capable of complex motion control (OTC Daihen)
  - Orbital welding tractor configured for inside welding (Magnatech Pipeliner)
- OTC robot welding system was used to develop baseline repair welding parameters
  - Transfer parameters to a more-suitable system for pipeline repair demonstrations
- API 5LX-52 – 22 in. diameter by 0.312 in. wall thickness

# Welding System Evaluation



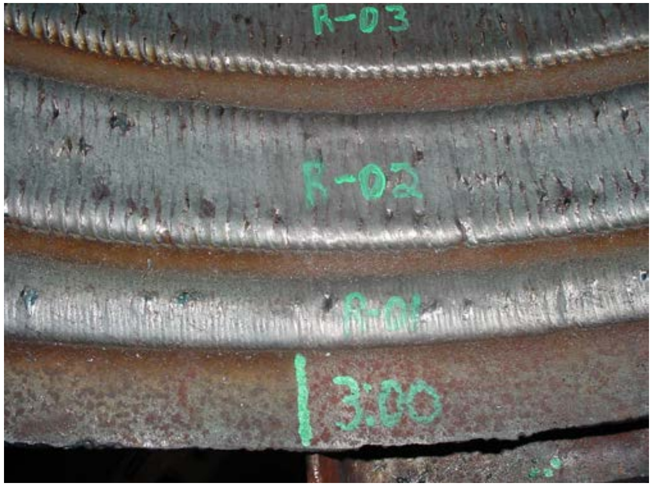
Bortech


OTC Robot


Magnatech

# Ideal Weld Bead Shape

- Uniform thickness across weld section except near weld toes which should taper smoothly into the base material
  - Smooth toes promote good tie-ins with subsequent weld beads
- The fusion boundary should be uniform and free from defects




- Preliminary tests were also performed to evaluate bead overlap and tie-in parameters that would be required to make high quality repairs

# Further Development of Weld Deposition Repair

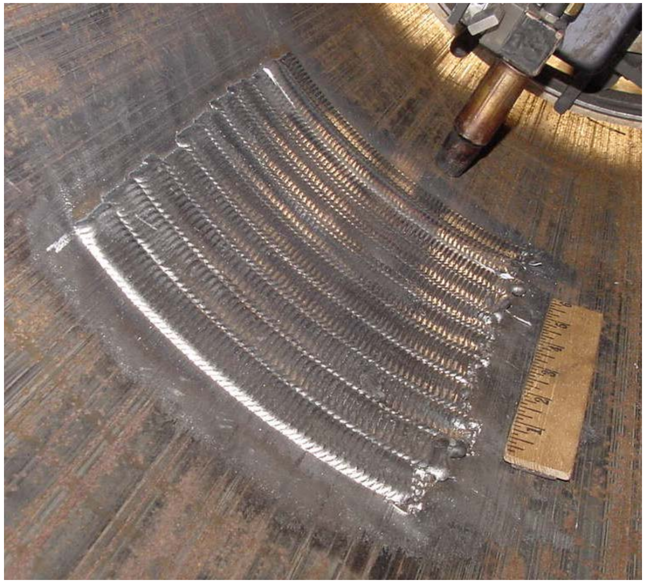
- Transfer welding parameters developed using OTC robot to Magnatech system
- Repair of simulated corrosion damage (soil box)
  - Evaluate heat transfer to the surrounding soil
  - Evaluate effect of internal weld deposition repair on coating integrity
- Hydrostatic pressure testing of completed repairs
  - Evaluate ability of weld metal deposited on the inside to reinforce damage on the outside of the pipe
- Effect of trace amounts of methane in the welding environment on the integrity of completed repairs

# Weld Repair Experiment

- Pipe material
  - 22 in. diameter by 0.312 in. wall thickness API 5L-Grade B (1930's vintage)
- Simulated corrosion damage
  - 7.5 in long by 0.156 in. deep
  - 25% reduction in predicted burst pressure

# Deposition of Repair

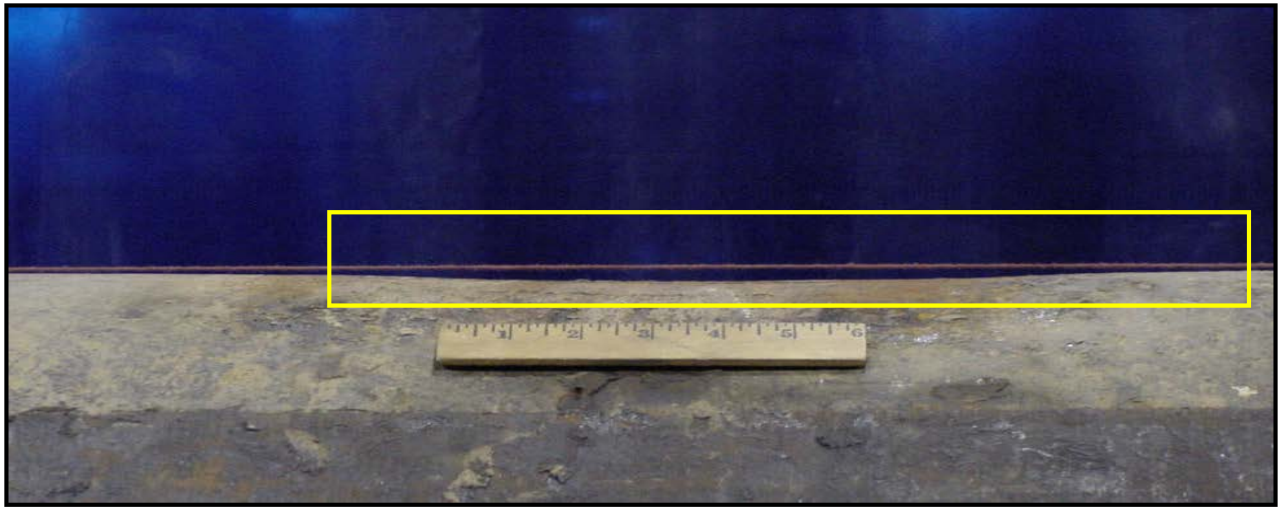
- Soil box to simulate heat transfer to the surrounding soil
- Two layers of weld metal
  - After-repair minimum wall thickness > nominal wall thickness



# Evaluation of Completed Repair

- Ultrasonic wall thickness measurements
  - Several areas of lack-of-fusion defects were detected between the weld toes of the first layer and the inside diameter of the pipe
  - Considered inconsequential given their size and circumferential orientation
- Visual examination
  - Asphalt coating melted and transferred to the surrounding soil during the welding process
  - Significant welding distortion from weld heating and cooling cycles resulted in out-of-roundness

# Coating Transfer and Welding Distortion



# Weld Distortion

- When applied to the outside of an exposed pipeline, dents or concavity that result from welding residual stresses can be overcome by simply applying more weld metal until the outside diameter of the pipe is restored

# Hydrostatic Pressure Testing

- Burst test for pipe w/out damage
- Burst test for pipe w/un-repaired damage
- Burst test for pipe w/repair

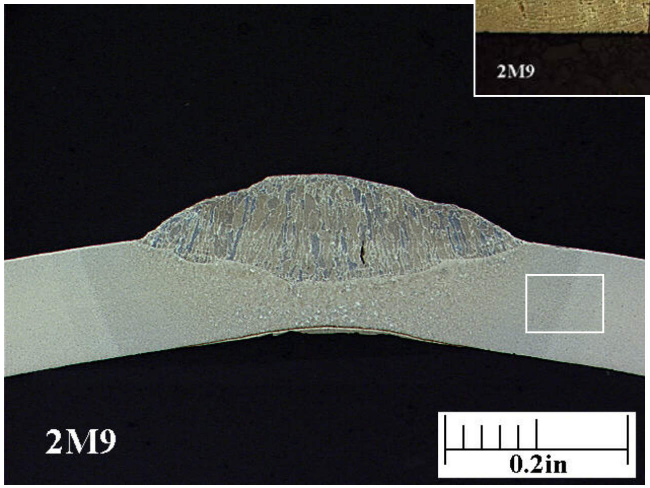
# Burst Test Results For Pipe w/Repair

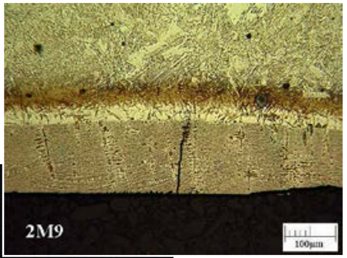
# Pressure Testing Results – Weld Repair

- Pressure at 100% SMYS – 992 psi
- Burst pressure for pipe w/out damage – 1,841 psi
- Burst pressure for pipe w/un-repaired damage – 1,563 psi
  - 15% reduction from pipe w/out damage
- Burst pressure for pipe w/repair – 1,404 psi
  - 10% reduction from pipe w/un-repaired damage
  - 42% improvement from pressure at 100% SMYS
  - 23% reduction from pipe w/out damage

# Effect of Methane In Welding Environment

- Survey results indicate that operators have a strong preference for repair methods that can be applied while the pipeline remains in service
- When steel at high temperature is exposed to a hydrocarbon gas (e.g., methane), carburization can occur and eutectic iron can form
- For internal in-service repair, methane may need to be excluded from welding environment

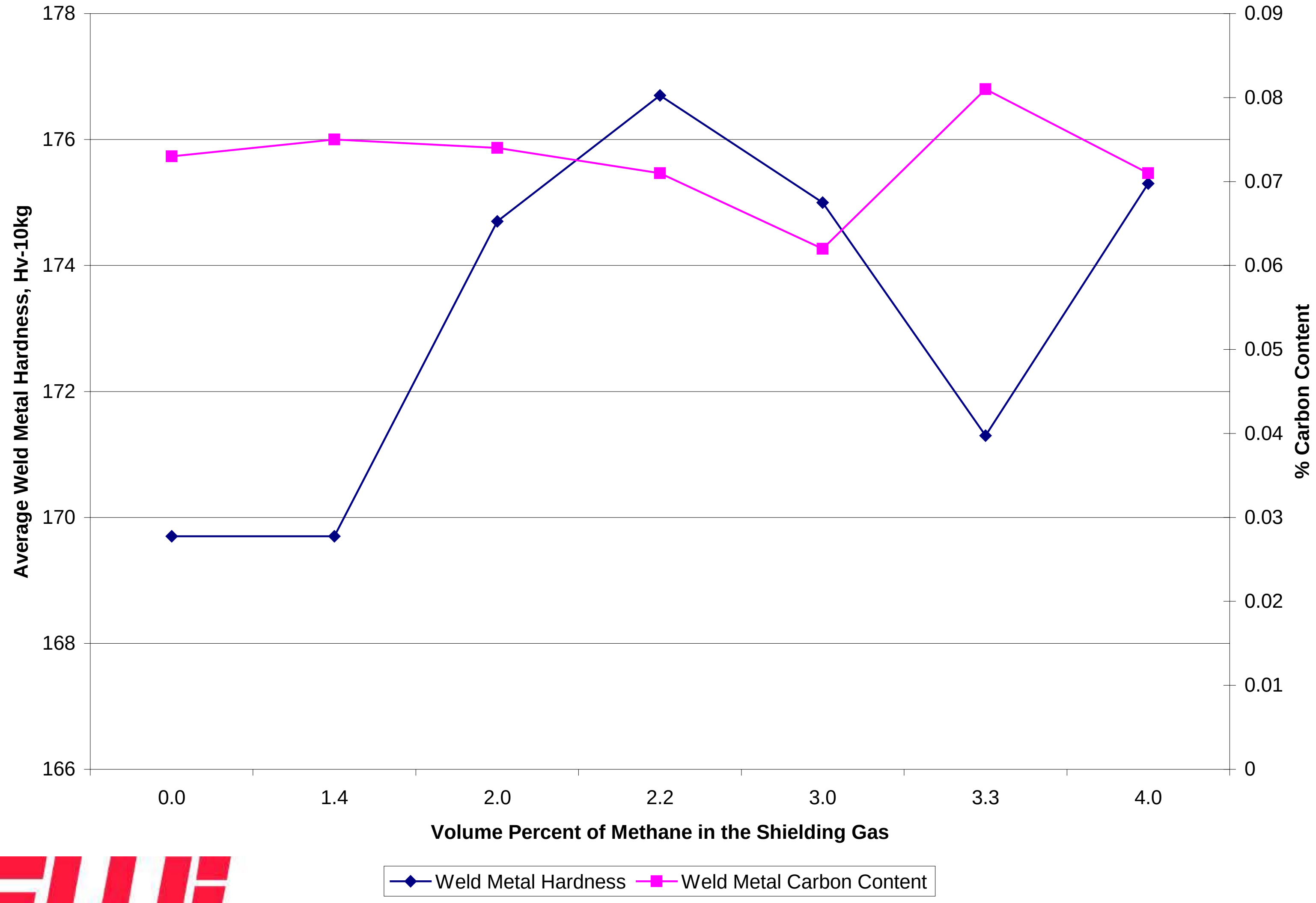


# Effect of Methane Welding Trials

- Weld trials were conducted with various levels of methane in the shielding gas
  - Determine the effect of methane on weld quality
  - 0 to 4.0 volume percent of methane
- Analysis
  - Metallographic examination
  - Weld metal hardness measurements
  - Weld metal chemical composition

# Effect of Methane in Shielding Gas

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# Results of Methane in Shielding Gas Trials

- No systematic variation in weld metal carbon content or weld metal hardness as a function of volume percent of methane in shielding gas
- Weld metal porosity occurs at volume percent of methane of 3.0 and higher

# Disposition of Weld Repair Activities

- Weld deposition, although promising in principal, is less than ideal for internal repair of gas transmission pipelines
  - Dents or concavity result from welding residual stresses
  - Difficulties arise from remotely operating welding equipment from great distances
  - Presence of methane in welding environment presents additional difficulties
- Activities pertaining to development of weld repair methods were suspended in favor of those related to fiber reinforced composite repairs

# Further Development of Fiber-Reinforced Composite Repairs

- Determine realistic combinations of carbon fiber composite material properties and thickness for use in liner systems for internal repair of natural gas transmission pipelines
- Engineering analysis was employed to arrive at the composite requirements for economical carbon fiber/vinylester resin system
- It was determined that the composite material should be on the order of 0.45 in. thick to approximate the stiffness of the steel while still maintaining a reasonable interlaminar shear strain

## Engineering Analysis

- Two simple cases were investigated
  - Entire steel pipe has been lost to external corrosion, leaving only the liner to carry the external stress
  - Shear failure occurs in the matrix material between the layers of fibers
- Pipeline size chosen to be in the middle of the commonly used range for transmission pipelines
  - 20 in. diameter by 0.25 in. wall thickness
- Liner material can not be so thick as to prevent subsequent examinations by internal inspection devices
  - Limited to less than 0.5 in.

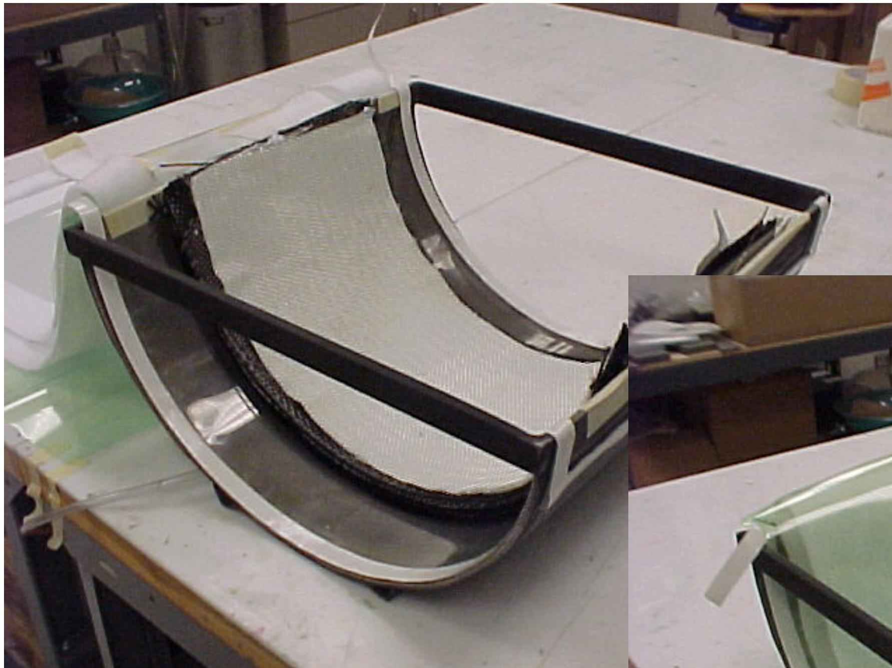
# Resulting Composite Material – Design No. 1

- Standard 6K-tow, 5-harness weave carbon fiber fabric and a vinylester resin, catalyzed with methyl ethyl ketone peroxide (MEKP) and promoted with cobalt naphthenate
- Fabric cut to give a quasi-isotropic lay-up with +/- 45 degrees for the outer layers, interleaved with 0 - 90 degree layers
- 20 oz. woven roving, glass fabric outer layer was employed for the outer faces of the composite material
  - Included to act as a galvanic corrosion barrier between the carbon fiber composite and the steel.

# Fabrication of Composite Patch – Design No. 1

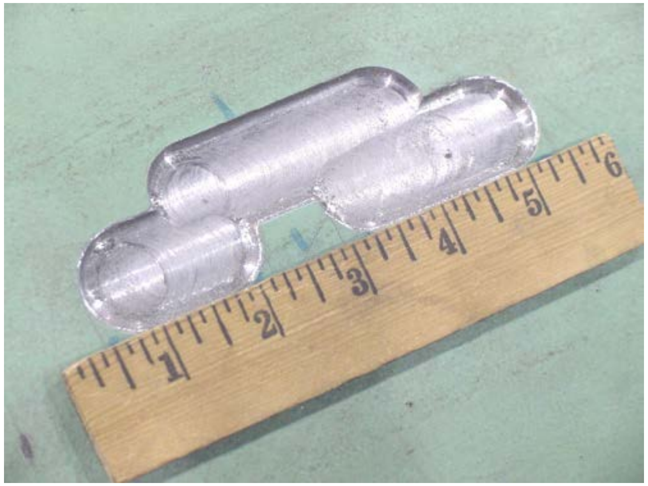
- Fabricated using a wet lay-up process followed by vacuum bagging
- The half-round composite patch had an outside diameter that matched the inside diameter of the pipe section
  - 10 in. in length, 28 in. wide, 0.45 in. thick
  - 27 layers; layers 1 and 27 were glass woven roving
  - Remaining layers consisted of alternating layers of +/- 45 degree and 0 - 90 degree (fiber orientation) carbon fiber fabric
- Calculated fiber volume was 40% - 45%.

# Wet Lay-up Followed by Vacuum Bagging



# Composite Patch Experiment – Design No. 1

- Pipe material
  - 20 in. diameter by 0.250 in. wall thickness API 5L-52
- Simulated corrosion damage
  - 5.0 in long by 0.136 in. deep
  - 25% reduction in predicted burst pressure



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# Installation of Patch

- Grit-blasting using 50 - 80 grit Alumina
  - Inside surface of pipe
  - Outside of Patch to remove surface resin
- Liberal coating of 3M DP460 epoxy adhesive was applied to the internal faying surface and a thin coating was applied to the patch faying surface
- Patch was positioned and held in place using bar clamps

# Installation of Patch

# Installation of Patch

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# Hydrostatic Pressure Testing

- Protocol
  - Burst test for pipe w/out damage (virgin pipe)
  - Burst test for pipe w/un-repaired damage
  - Burst test for pipe w/repair

Pipe w/out damage

Pipe w/un-repaired damage

# Pressure Testing Results – Composite Patch Design No. 1

- Pressure at 100% SMYS – 1,300 psi
- Burst pressure for pipe w/out damage – 2,325 psi
- Burst pressure for pipe w/un-repaired damage – 2,112 psi
  - 9% reduction from pipe w/out damage
- Burst pressure for pipe w/repair – 2,194 psi
  - 4% improvement from pipe w/un-repaired damage
  - 69% improvement from pressure at 100% SMYS
  - 6% reduction from pipe w/out damage

# Burst Test For Pipe w/Repair

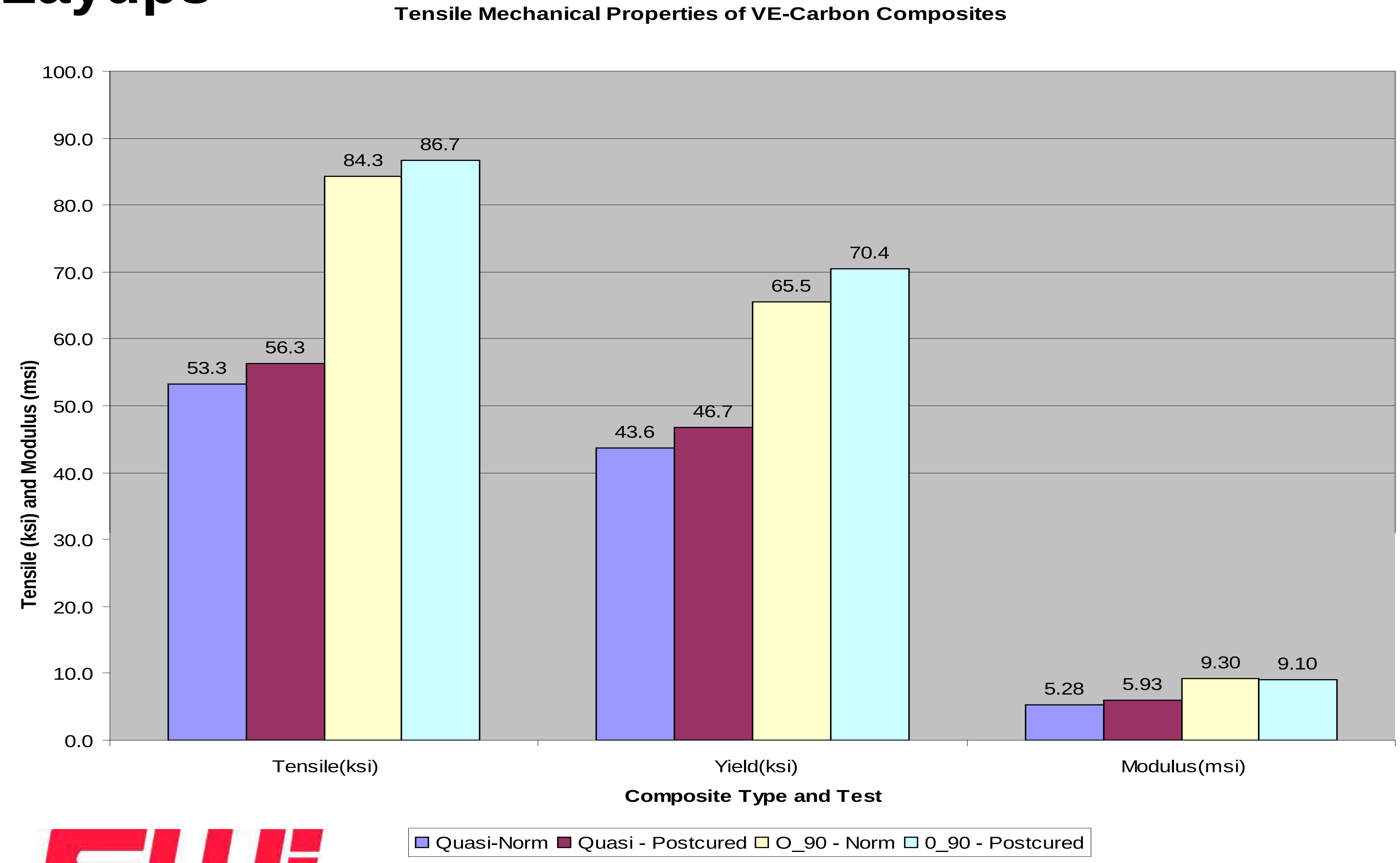
# Post Mortem Analysis

- Failure was caused by interlaminar shear mostly between the anti-corrosion glass layer and the carbon layer
  - 1 $\rightarrow$ 2 layer interfacial failure is common in composites
- No evidence of disbonding between the pipe and the composite liner.

# Optimization of Patch Design

- Additional engineering analysis was employed optimize the requirements for carbon fiber-based repair system
- Composite design requirement is based on:
  - Strength
  - Modulus
  - Thickness
- Composite performance is based on:
  - Interlaminar shear (resin failure between layers predominates)
  - Modulus (bending under load generates interlaminar shear)
  - Thickness (to provide adequate stiffness to operate the load point below the interlaminar shear value)

# Mechanical Properties with Quasi-Iso and 0,90 Layups

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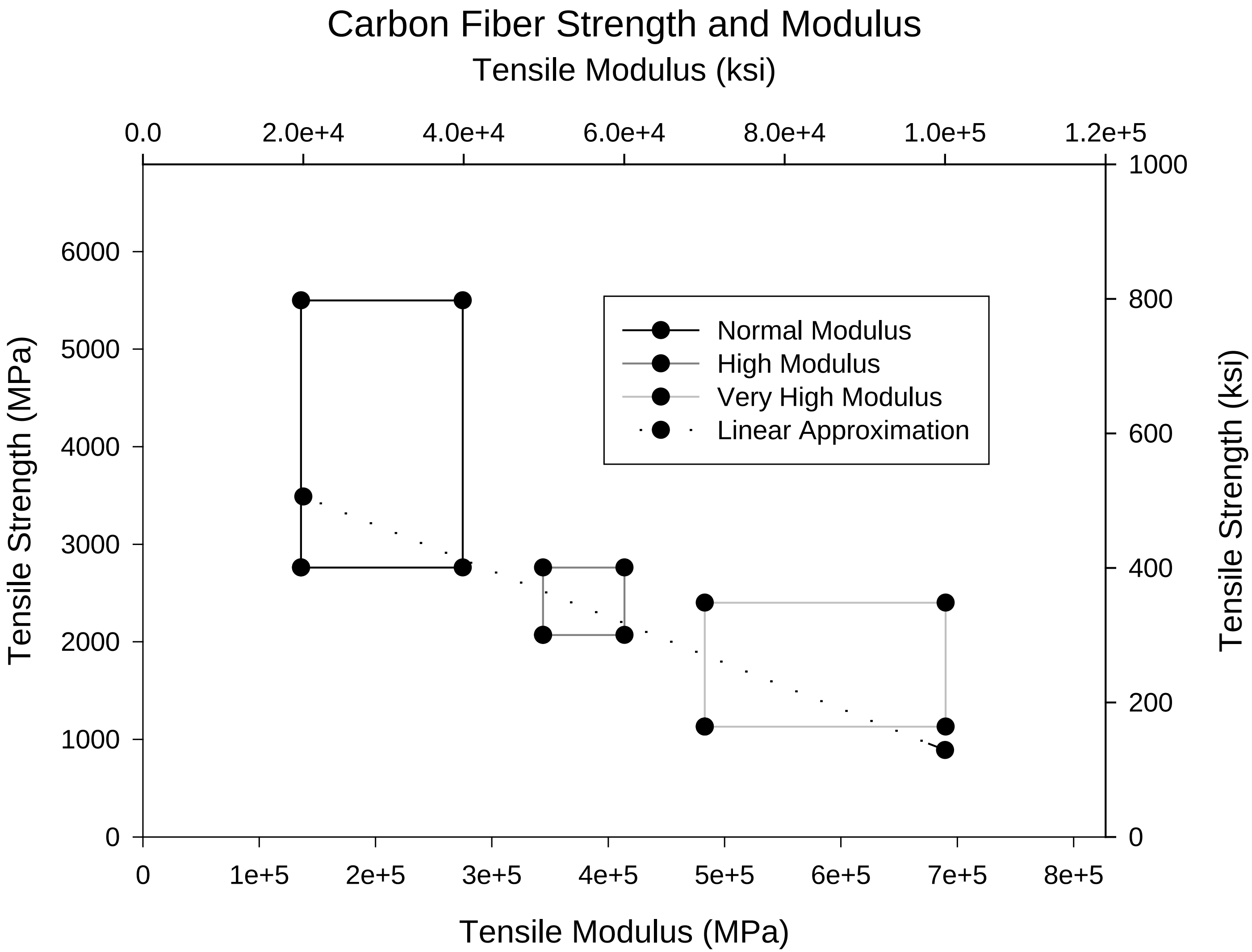
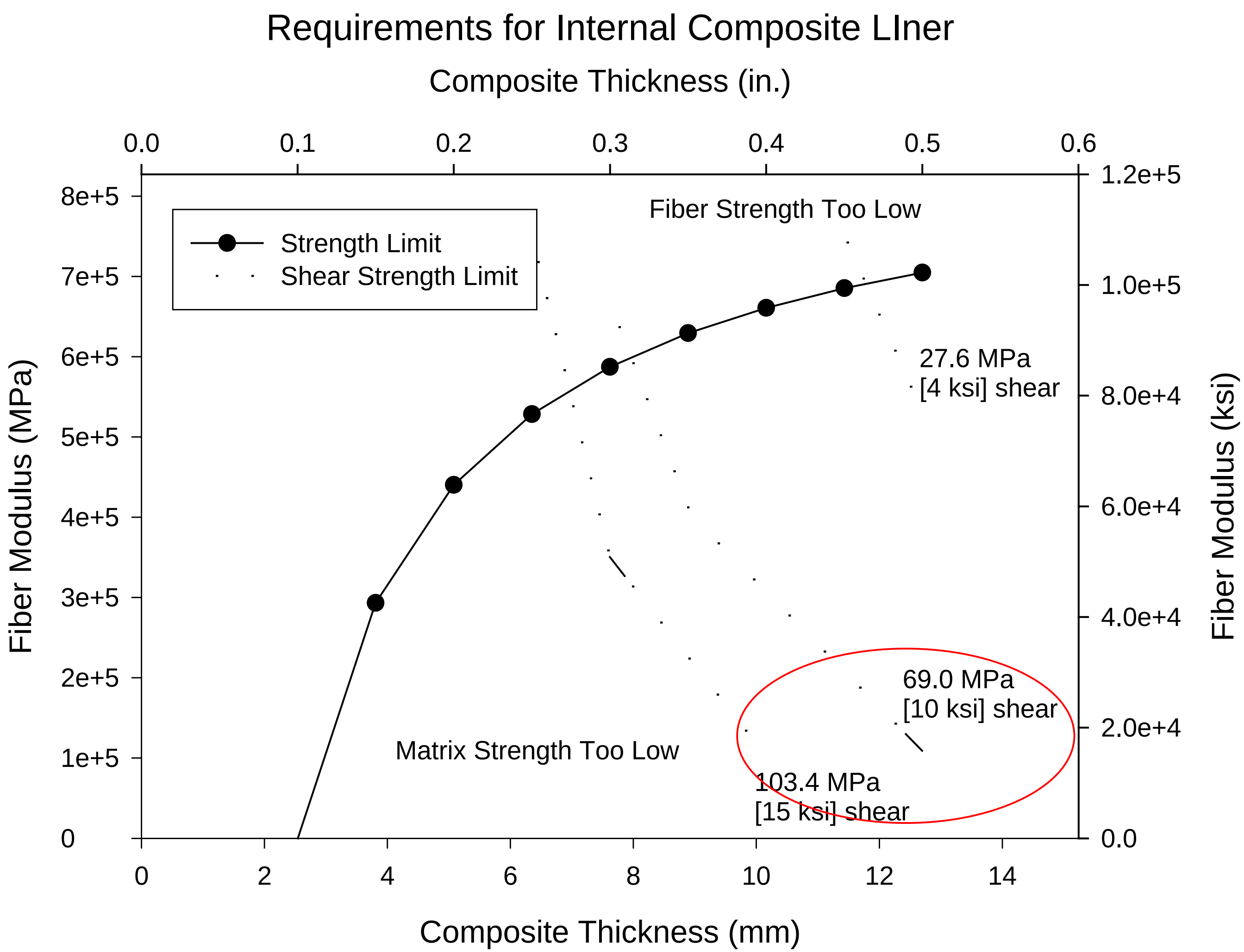
# Results from Mechanical Testing

- Replacing quasi-isotropic layup with 0,90-layup increases:
  - Ultimate tensile by 80%
  - 0.2% Yield by 50%
  - Modulus by 80%
- With all 0,90 layup:
  - Density remains the same at about 1.5
  - Fiber content remains about 50-55 vol-%
  - No change in interlaminar shear (ILS)
  - No effect of postcuring
- Testing also showed the ILS to be much lower than anticipated: 1.3 ksi vs. 5-7 ksi (but the patch still worked)

# Optimization of Patch Design – Performance Field



# Design Space for Composite Liner – Thickness

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# Higher Modulus Composite Patch – Design No. 2 (thick)

- Use all 0,90 construction and reduced thickness to take advantage of higher modulus
- Fabricated using same process as before (all 0,90)
  - 10 in. in length, 28 in. wide, 0.45 in. thick
  - 27 layers; layers 1 and 27 were glass woven roving
- Calculated fiber volume was 50% -55%.

# Higher Modulus Composite Patch Experiments – Design No. 2 (thick) and 3 (thin)

- Pipe material
  - 20 in. diameter by 0.250 in. wall thickness API 5L-X52 (same specification as before but different pipe material)
- Simulated corrosion damage
  - 5.0 in long by 0.136 in. deep
  - 25% reduction in predicted burst pressure

# Pressure Testing Results – Higher Modulus Composite Patch – Design No. 2 (thick)

- Pressure at 100% SMYS – 1,300 psi
- Burst pressure for pipe w/out damage – 2,122 psi
- Burst pressure for pipe w/un-repaired damage – 1,298 psi
  - 39% reduction from pipe w/out damage
- Burst pressure for pipe w/repair – 1,777 psi
  - 37% improvement from pipe w/un-repaired damage
  - 37% improvement from pressure at 100% SMYS
  - 16% reduction from pipe w/out damage

# Post Mortem Analysis

- Repair was sectioned in the circumferential direction
- Ultimate failure of the patch was the result of interlaminar shear
- Failure appears to have occurred after the steel reached the plastic range (i.e., after the yield point of the steel was exceeded)

# Higher Modulus Composite Patch – Design No. 3 (thin)

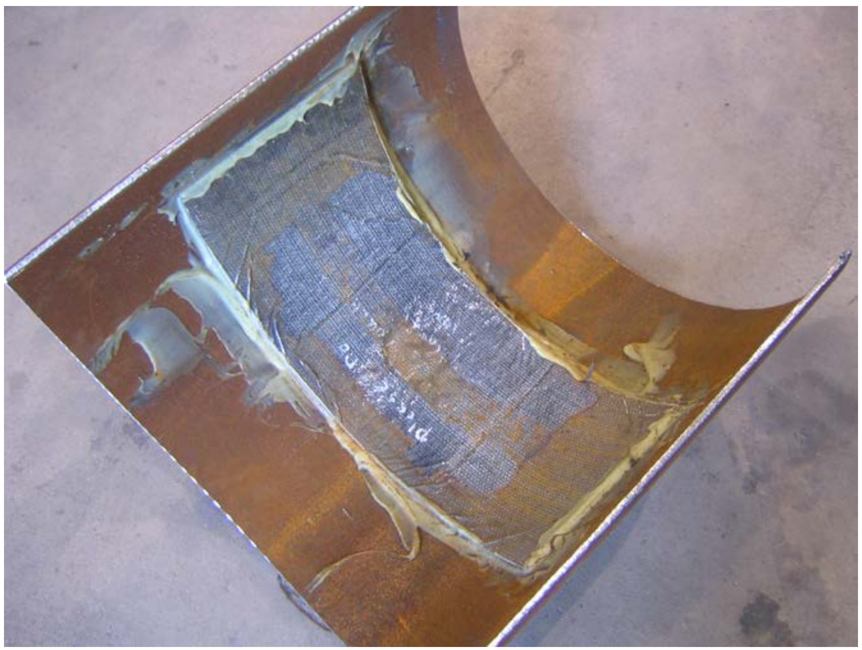
- Encouraging results were obtained using higher modulus carbon fiber patch (thick - all 0,90 construction)
- Repeat experiment to determine ability of thinner patch to restore pressure-containing ability
- Use all 0,90 construction and reduced thickness to take advantage of higher modulus
- Fabricated using same process as before (all 0,90)
  - 10 in. in length, 28 in. wide, 0.3 in. thick.
  - 18 layers; layers 1 and 18 were glass woven roving
- Calculated fiber volume was 50% - 55%

# Pressure Testing Results – Higher Modulus Composite Patch – Design No. 3 (thin)

- Pressure at 100% SMYS – 1,300 psi
- Burst pressure for pipe w/out damage – 2,122 psi
- Burst pressure for pipe w/un-repaired damage – 1,298 psi
  - 39% reduction from pipe w/out damage
- Burst pressure for pipe w/repair – 1,730 psi
  - 33% improvement from pipe w/un-repaired damage
  - 33% improvement from pressure at 100% SMYS
  - 19% reduction from pipe w/out damage

# Higher Modulus Composite Patch – Design No. 3 (thin)

- Results similar to those for thicker patch
- Postmortem analysis underway



# Long-Shallow Defects

- The length beyond which hoop stress can no longer distribute hoop stress beyond the ends is:
  - L = 20dt^1/2
  - For 20 in. diameter by 0.250 in. wall thickness pipe, L = 10 in.
- Perform experiment to determine the ability of carbon fiber-based repair system to restore pressure-containing ability of pipe with long-shallow defect

# Higher Modulus Composite Patch Experiments – Design No. 3 – Long-Shallow

- Pipe material
  - 20 in. diameter by 0.250 in. wall thickness API 5L-52
- Simulated corrosion damage
  - 15 in long by 0.100 in. deep
  - 25% reduction in predicted burst pressure


# Higher Modulus Composite Patch for Long-Shallow Defect – Design No. 3

# Pressure Testing Results – Higher Modulus Composite Patch – Design No. 3 - Long-Shallow

- TESTING UNDERWAY
- Pressure at 100% SMYS – 1,300 psi
- Burst pressure for pipe w/out damage – 2,122 psi
- Burst pressure for pipe w/un-repaired damage – 1,473 psi
  - 31% reduction from pipe w/out damage
- Burst pressure for pipe w/repair – _____ psi
  - __% improvement from pipe w/un-repaired damage
  - __% improvement from pressure at 100% SMYS
  - __% reduction from pipe w/out damage

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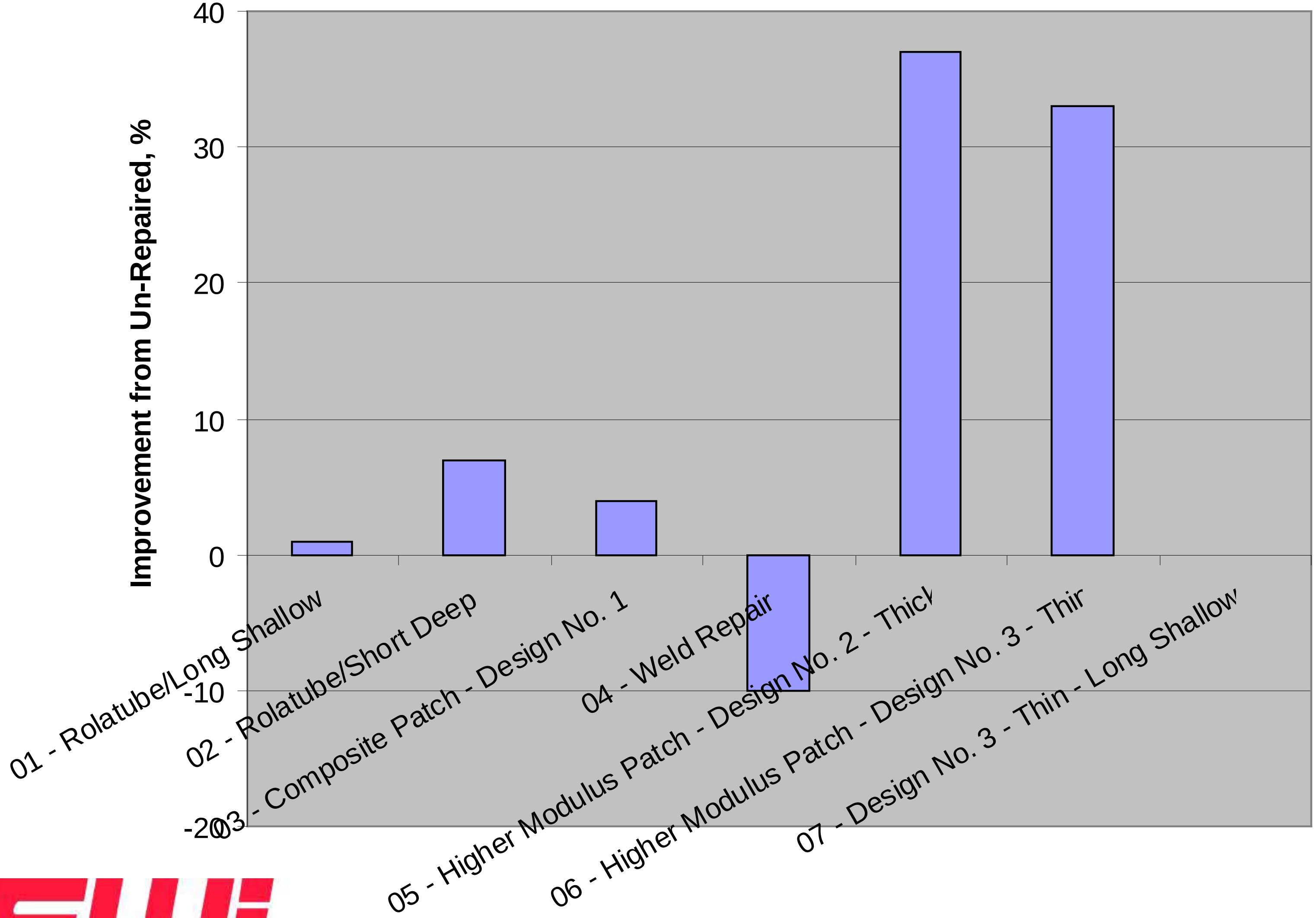
# Burst Test Series Conducted to Date

- 01 – Rolatube - Long Shallow
- 02 – Rolatube - Short Deep
- 03 – Composite Patch – Design No. 1
- 04 – Weld Repair
- 05 – Higher Modulus Composite Patch – Design No. 2
- 06 – Higher Modulus Composite Patch – Design No. 3
- 07 – Higher Modulus Composite Patch – Design No. 3 – Long Shallow Damage

# Summary of Burst Test Results

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# Summary of Composite Repair Experiments

- Carbon fiber-based composite repair system has the potential to significantly improve the strength of damaged pipe
- When pipe material begins to yield, matrix material fails by interlaminar shear allowing pressure to act upon the defect
  - Burst pressure for pipe repaired using fiber-reinforced composite materials may never reach burst pressure for pipe w/out damage
- Burst pressures for damaged pipe repaired by carbon fiber-based repair system are significantly greater than pressure at 100% SMYS

# Old Subtask 5.4
## *Perform Field Trials on Abandoned Pipeline*

- When proposal submitted, weld deposition repair assumed to be most appropriate repair process
- Therefore, performing field trials on an abandoned pipeline was part of the plan for several reasons, as it is the best place to:
  - Study the issue of sending electrical power over distances in excess of 304.8 m [1,000 ft]
  - Study the affect of welding heat input on extant pipeline coatings
  - Study the affects of soil induced cooling rates on resultant weld microstructure and the parameters necessary to produce a weld with an acceptable quality level

# Old Subtask 5.4
## *Perform Field Trials on Abandoned Pipeline*

- Carbon fiber-reinforced composite repair is most promising repair
- Trials on abandoned pipeline is no longer worthwhile, since:
  - Carbon fiber-reinforced repairs is currently a manual process
    - No long distance delivery of electrical power required
  - Pipeline coatings will not be affected by the repair
  - Repair process not affected by the soil surrounding the pipeline
- This task would be viable if testing a prototype tooling system that installs the carbon fiber-reinforced liner repair
- Since repair process is manual, it can be demonstrated at EWI with the same methods required by a field trial.

# New Subtask 5.4
# Develop Preliminary Post Repair NDE Protocol

- Develop a detailed preliminary NDE protocol to verify effectiveness of repair
- Protocol
  - Propose NDE method to determine success or failure of the repair
  - Address any potential problems which may need to be addressed in repair verification testing

# New Subtask 5.4
# Develop Preliminary Post Repair NDE Protocol

- Create a test repair patch using carbon fiber-reinforced repair with several types and sizes of anticipated defects built into the adhesive bond
- Create calibration blocks for each NDE method
- Evaluate the ability of several NDE inspection methods to capture the defects in the repair sample
- Identify the NDE process with the highest accuracy and repeatability for the application
- Research recommended NDE process to identify potential problems which may need to be addressed in repair verification testing
- Report results

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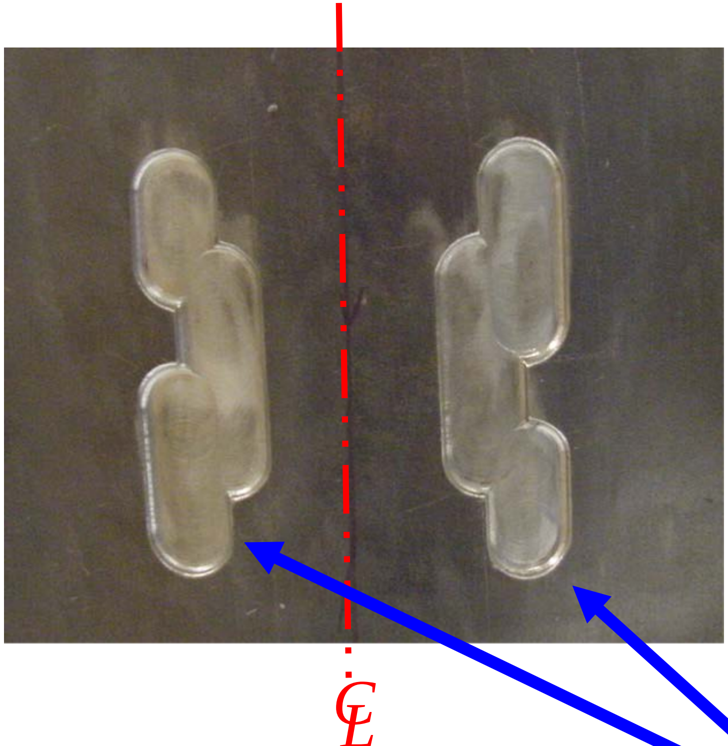
# Test Repair Patch with Known Defects

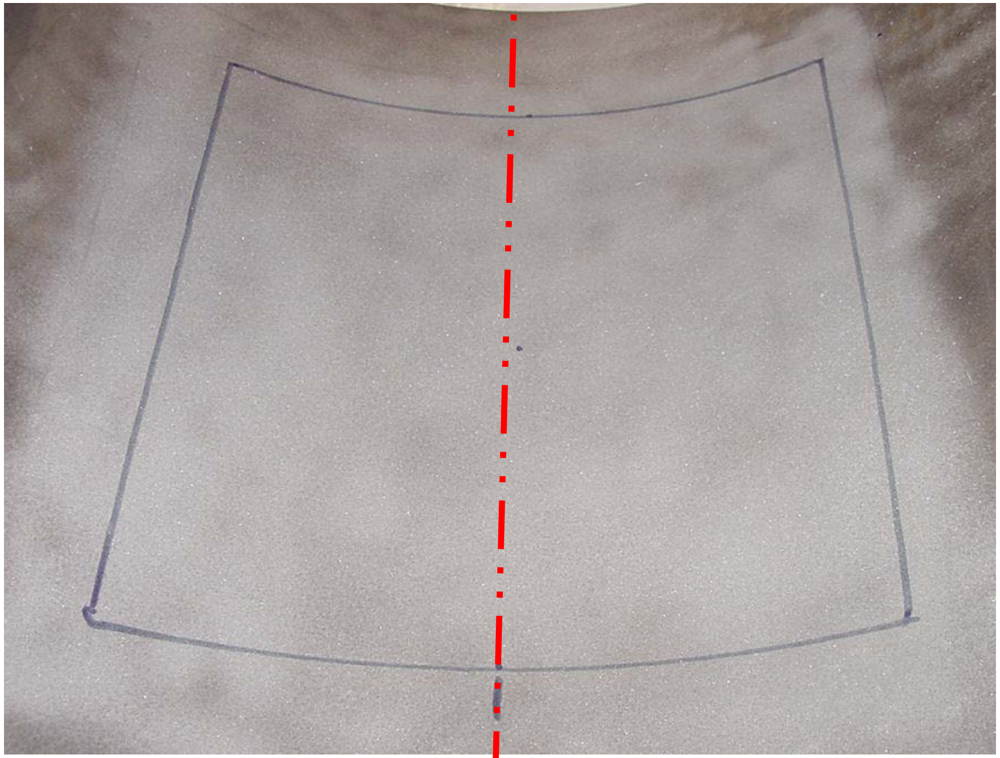


Outside Surface of Pipe

- Pipe Characteristics
  - 20 in. diameter
  - ¼ in. wall
  - X52

**(2) areas of simulated corrosion on either side of pipe centerline**

# Test Repair Patch with Known Defects



Inside Diameter Shot Blasted to Prepare Surface for Bond

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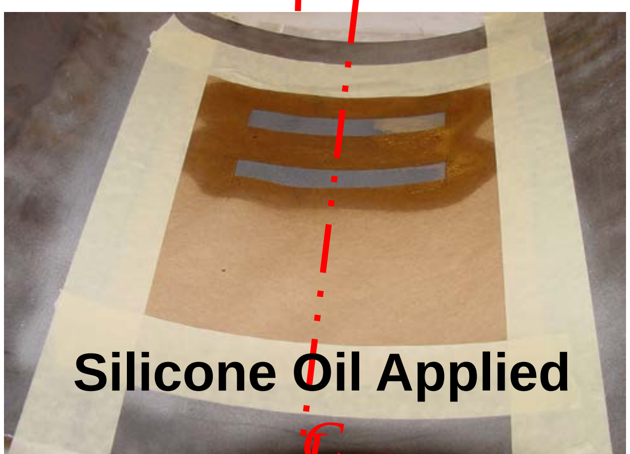
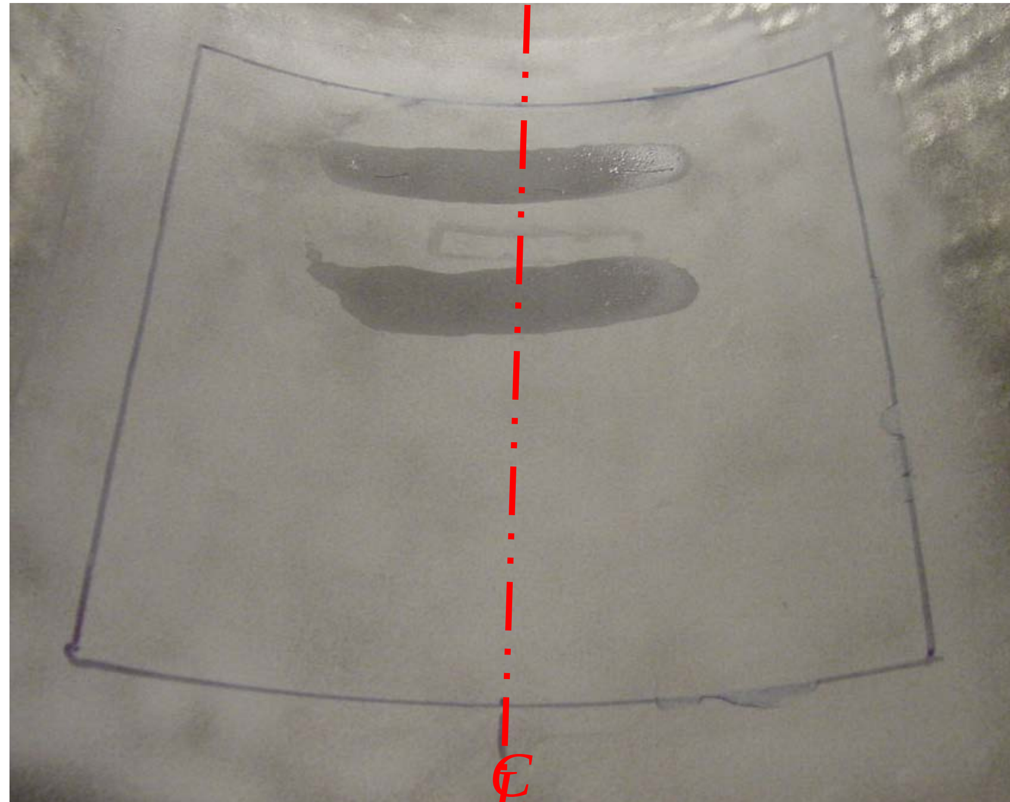
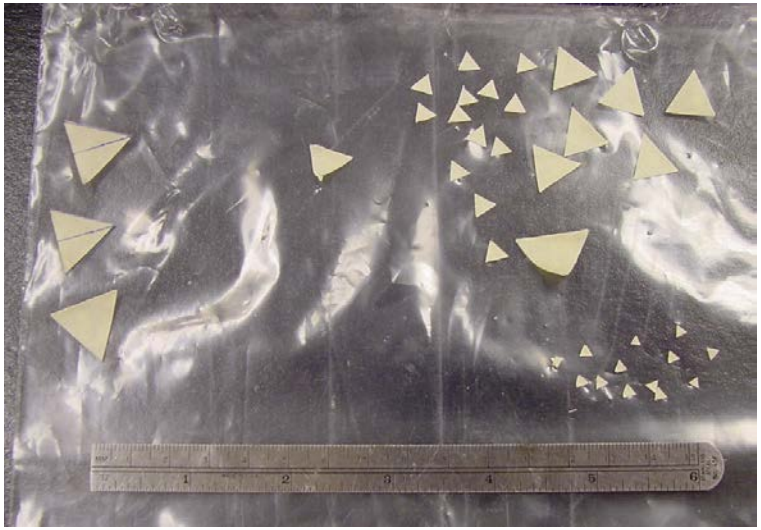
# Disbond Area Preparation

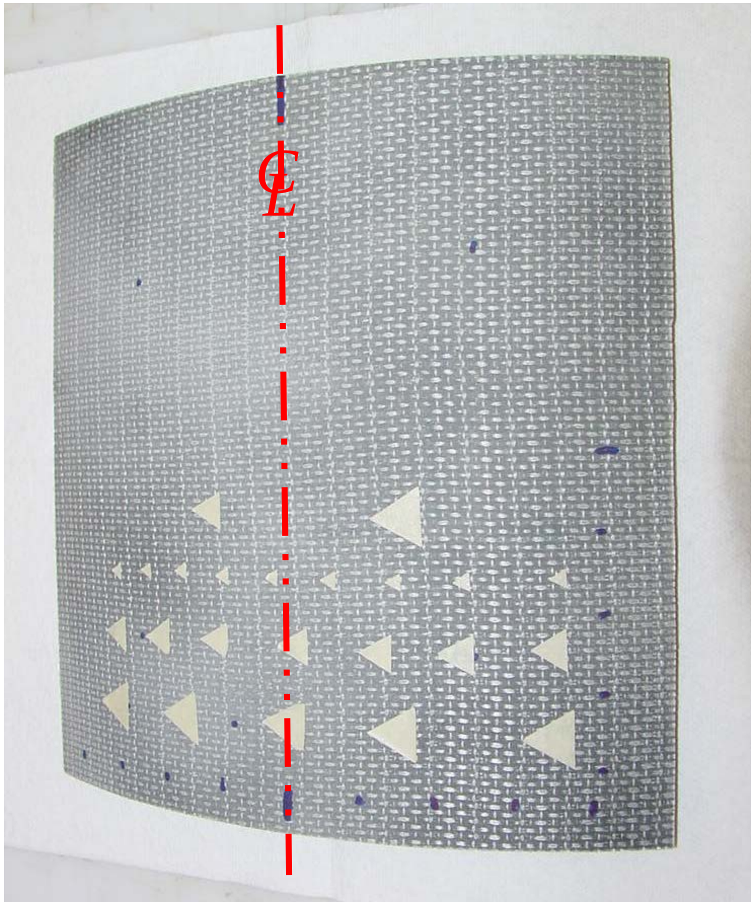



**Silicone Oil applied to Pipe to simulate Disbond between Pipe and the Adhesive**

# Defect Preparation

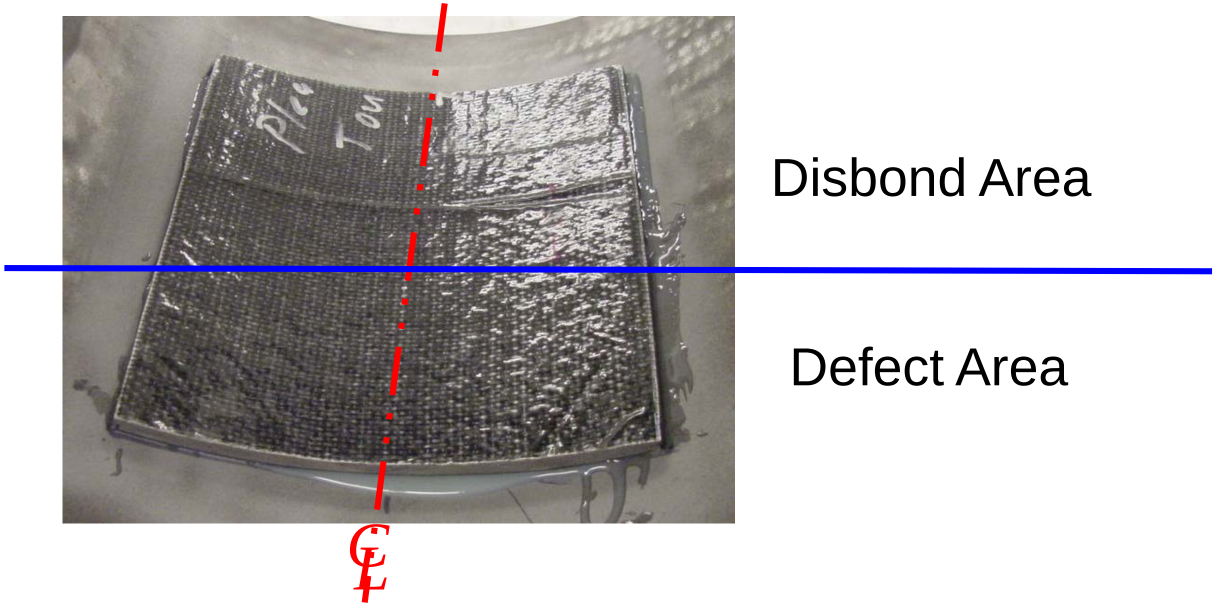


- Defects made from masking tape
- Defects affixed to Patch to simulate defects between Patch and the Adhesive



**Defect Locations on Patch**

# Test Repair Patch with Known Defects




- Adhesive = 3M DP460 Epoxy
- Patch (thick 0,90) = 6K-tow, 5-harness weave carbon fiber fabric and a vinylester resin (FiberGlast 1110 vinylester resin), catalyzed with methyl ethyl ketone peroxide (MEKP) and promoted with cobalt naphthenate.

# Evaluation of NDE Methods

- NDE must be applied from ID not OD
- Techniques
  - Ultrasonics
  - Electromagnetics

# Ultrasonic Testing (UT)

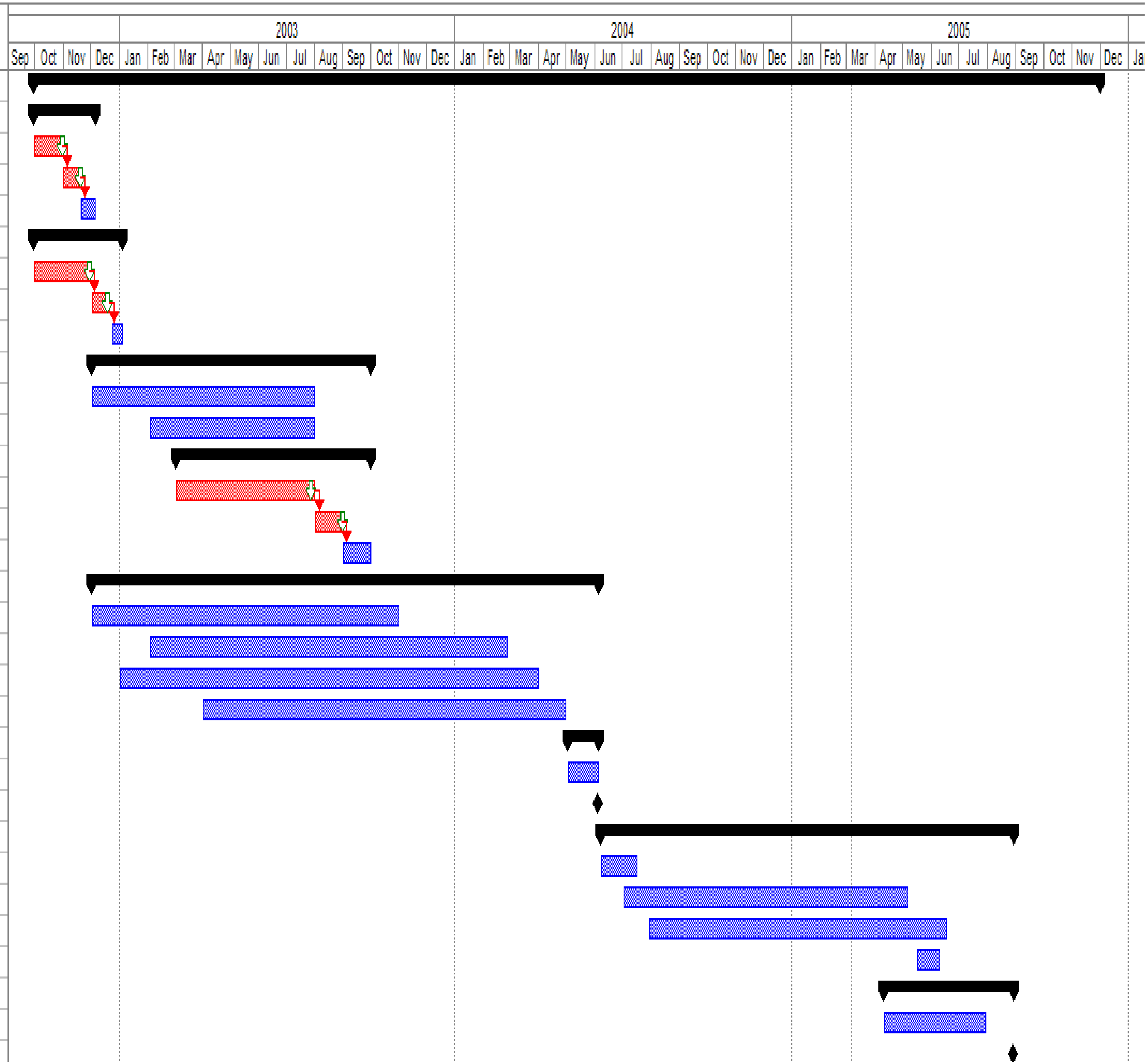
- Use specialized pulse-echo and phased array UT equipment for mapping of corrosion damage in the tube steel wall and detection of interface defects
- The feasibility study with UT method will involve laboratory trials using low frequency:
  - Single focused probes
  - Dual probes
  - Single linear and dual linear phased array probes
  - Single matrix and dual matrix phased array probes

# Electromagnetics/Eddy Current (EC)

- Use specialized EC equipment for mapping of corrosion damage in the tube steel wall
- The feasibility study with EC method will involve:
  - Design of high-power low-frequency probe through computer modeling and simulation
  - Probe and accessories manufacture
  - Laboratory trials on experimental specimen with repair patch and artificial corrosion damage

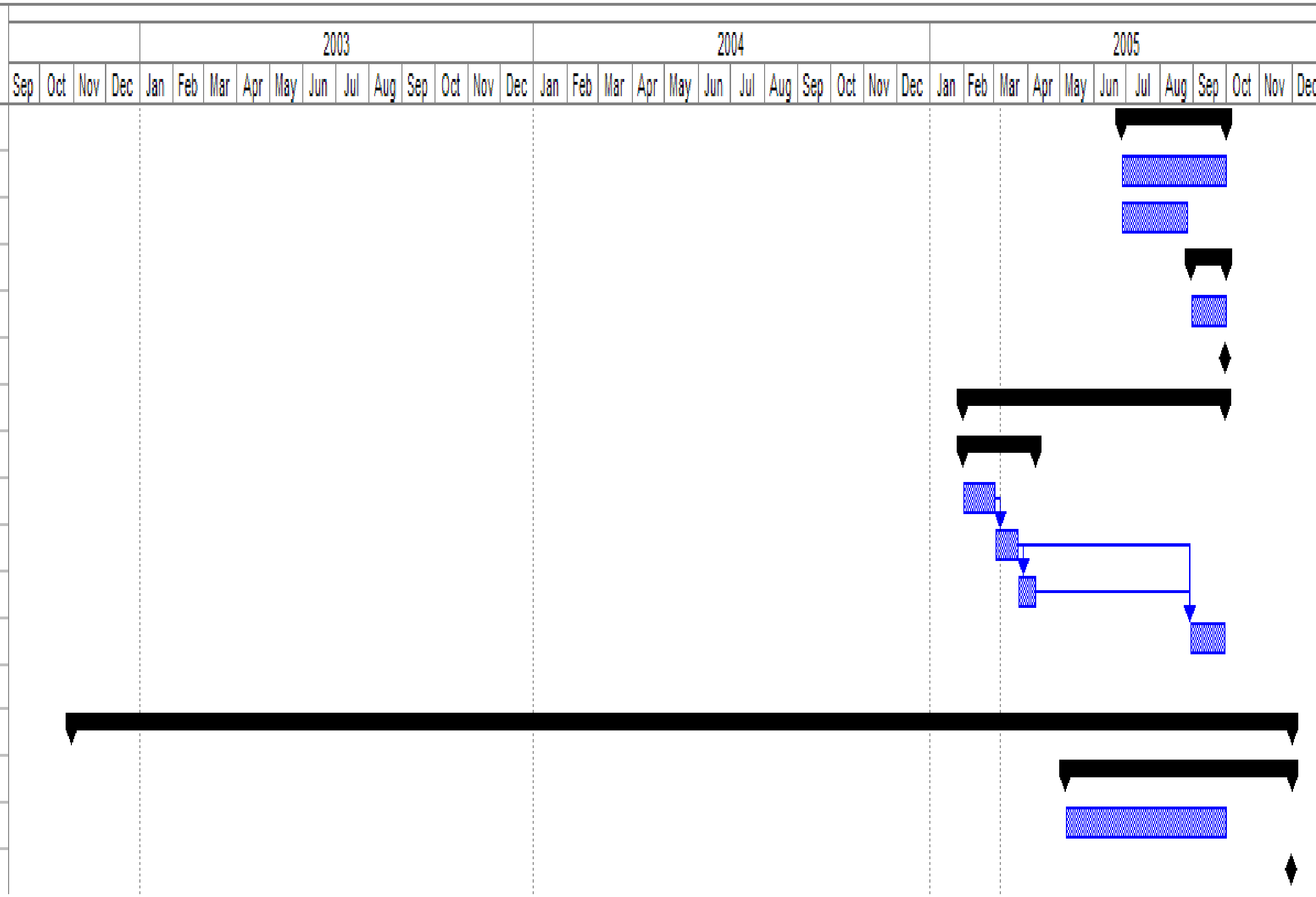
# Review of Project Plan

| ID | Task Name |
|---|---|
| 1 | Internal Repair of Pipelines |
| 2 | 1.0 Research Management Plan |
| 3 | Draft Report to DOE COR |
| 4 | Input Received from DOE COR |
| 5 | Final Report to DOE COR |
| 6 | 2.0 Technology Status Assessment |
| 7 | Report Draft to DOE COR |
| 8 | Input Received from DOE COR |
| 9 | Final Report to DOE COR |
| 10 | 3.0 Review Operators Experience & Repair Needs |
| 11 | 3.1 Define Repair Needs Survey |
| 12 | 3.2 Define Target Specification |
| 13 | 3.3 Report on Industry Needs |
| 14 | Report Draft to DOE COR |
| 15 | Input Received from DOE COR |
| 16 | Final Report to DOE COR |
| 17 | 4.0 Evaluate Potential Repair Methods |
| 18 | 4.1 Identify Potential Repair Methods |
| 19 | 4.2 Devlop Internal Repair Test Program |
| 20 | 4.3 Simulation & Analysis |
| 21 | 4.4 Internal Repair Trials |
| 22 | 4.5 Report on Repair Trials |
| 23 | Prepare Report |
| 24 | Submit Report |
| 25 | 5.0 Optimize & Validate Internal Repair Methods |
| 26 | 5.1 Develop Test Program |
| 27 | 5.2 Optimization of Internal Repair Methods |
| 28 | 5.3 Full-Scale Lab Validation Trials |
| 29 | 5.4 Develop of Preliminary Post Repair Testing Protocol |
| 30 | 5.5 Report on Full-Scale Validation Tests |
| 31 | Prepare Report |
| 32 | Submit Report |



# Review of Project Plan

| ID | Task Name |
|---|---|
| 33 | 6.0 Develop Functional Specification |
| 34 | 6.1 Develop Target Specifications |
| 35 | 6.2 Review of IPNS |
| 36 | 6.3 Develop Functional Specification |
| 37 | Prepare Report |
| 38 | Submit Report |
| 39 | 7.0 Demo of Repair Technology |
| 40 | 7.1 Develop Plan for Demonstration |
| 41 | Demo Plan to DOE COR |
| 42 | Input & Approval Received from DOE COR |
| 43 | Final Plan to DOE COR |
| 44 | 7.2 Demonstration |
| 45 | |
| 46 | Reporting Requirements |
| 47 | Final Technical Report |
| 48 | Prepare Report |
| 49 | Submit Report |

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# Demonstration Format

- Present project overview and major findings
- PG&E technician to manually install a carbon fiber-reinforced patch in a pipe section with simulated damage
- An identically repaired pipe section to be hydrostatically tested until rupture
- Failed pipe section can be inspected by participants
- Other failed pipe sections will be displayed
- Technology demo will be video taped

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# Demonstration Format

- Demonstration testing will be conducted on a full scale pipe assembly with damage sufficient to demonstrate the true effectiveness of the repair technology on representative pipeline damage.
- NETL COR will be invited to witness demonstration testing.
- The demonstration testing results will be compiled, analyzed and included as a portion of the test results in the project final report.

# Planned Activities

- Complete activities related to optimization of composite repair system
- Develop preliminary post repair NDE protocol
- Perform technology demonstration
- Report

# Summary and Conclusions

- Internal repair methods are an attractive alternative to conventional repair methods since the need to excavate the pipeline is precluded
- Both weld deposition repair and fiber-reinforced composite liner repair were identified as attractive options for internal repair
  - Weld deposition, although promising in principal, is less than ideal for internal repair of gas transmission pipelines
  - Carbon fiber-based composite repair system has the potential to significantly improve the strength of damaged pipe
- Further activities are planned

# Acknowledgements


- DOE for sponsoring this project and the staff at NETL for their guidance and support
- Project Team
  - Edison Welding Institute
    - George Ritter, Dave Speth, Marc St.John
    - Bill Mohr
    - Matt Boring, Gary Thompson, Jeremy Didion, Joe Dierksheide
    - Fabian Orth, Rich Minshall
    - Mark Lozev
  - Pacific Gas & Electric
    - Mike Sullivan, Chris Neary