PRCI Project NDE 2-3
NDE & Inspection Techniques Applied to Composite Wrap Repairs

PRCI Project No. PR-398-113705

Richard Lee, Steve Burch
& Martin Wall

ESR Technology, UK

2nd Annual Composite Repair Users Group

Conference & Exhibition Sept 7 2012, Houston, TX (Norris Conference Center)

PRCI
LEADING PIPELINE RESEARCH

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Executive Summary

Compile information on inspection of composite wrap repairs of relevance to the pipeline industry.

- Assess commercially available inspection methods to validate integrity of composite repair systems.
- Identify applicability to inspect composite overwrap and parent metal for both onshore and sub sea pipelines (where information is available)
- Identify sources of data to include other users of composite materials (aerospace/aircraft, naval/ship repairs).
- Identify procedures and technologies to assess inspection effectiveness and provide a gap analysis.
- Interface with other PRCI projects on long-term testing of composite repairs and other joint industry projects on composite repairs to improve our understanding of long term durability of repairs.
- Identify global experience with composite repairs – not just North America !

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Outline of Talk

1. *Introduction*
2. *Project Overview*
3. *State of the Art/Questionnaire responses*
4. *Gap Analysis*
5. *Coordination with HOIS and other activities including Standards organisations*
6. *Summary & Conclusions*
7. *Q&A*

(30 minutes)

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Project Overview
State Of The Art - Composite Wrap Repairs

Project Team

PRCI Mark Piazza (mpiazza@prci.org)

Co-Project Leaders

John O'Brien, Chevron jobrien@chevron.com
Mario Pezzi, Petrobras pezzi@petrobras.com.br

Consultants

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Steve Burch, ESR Technology steve.burch@esrtechnology.com
Martin Wall, ESR Technology martin.wall@esrtechnology.com

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ESR Scope of Work

- ESR Technology contracted by PRCI in July 2011 to compile information and available data on NDE and inspection of composite overwrap repairs for pipelines and other industries.

- Industry questionnaire issued on inspection/NDE to assess integrity of composite wrap repairs for operating pipelines. Survey carried out with members of the PRCI NDE 2-3 Project team (14 companies), HOIS members (37 companies) and Composite Repair Suppliers (20 companies).

- Link with existing PRCI projects and other initiatives in this area, i.e. interactions with other contractors e.g. Stress Engineering Services, Inc., ISO TC67/SC6 committee members responsible for the current ISO/TS 24817 standard on composite overwrap repairs. Attend Co-Patch meetings.

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Composite repair systems

Composite repairs consist, primarily, of the following materials;

Multiaxial Fabrics: Glass, Carbon, Aramid (e.g. Kevlar)

Resins (matrix): Epoxy, Polyester, Vinyl ester, Polyurethane

Adhesives: Epoxy, Methacrylates, Laminate resin systems

They are **hand applied** either using **wet lay-up** systems or **prefabricated rolls** of composite reinforcement bonded together on-site and allowed to cure.

Substrate **surface preparation** is key to long term durability

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Where can they be used? Oil & Gas

Piping systems

Pressure vessels

Caissons

Pipelines

All E & P service conditions are applicable, water, hydrocarbon and gas mostly used in topsides but repairs have been done sub-sea

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CFRP Pipe Repairs

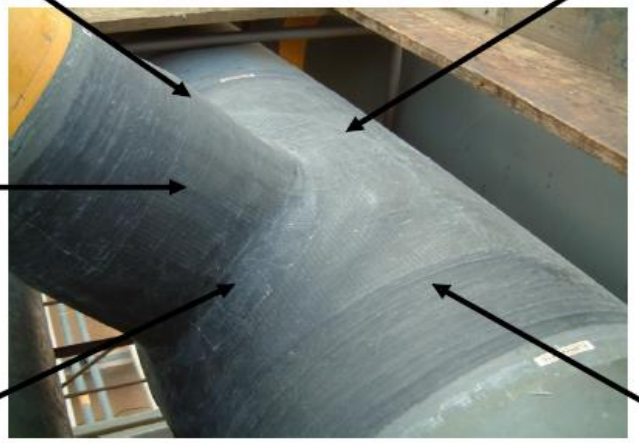
FURMANITE

CFRP Pipe Repairs

Materials formed to shape on site with no pre-fabrication

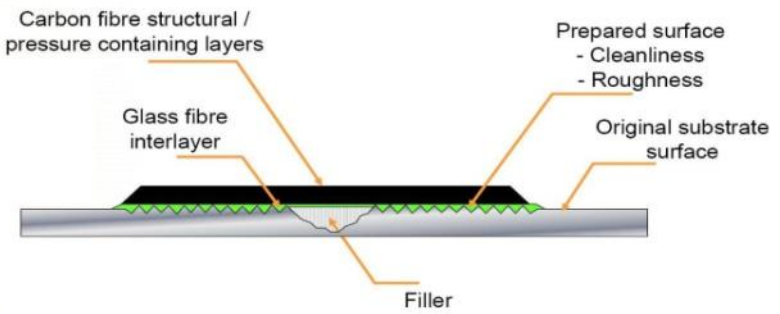
Flexible materials conform to difficult shapes

Epoxy bond to steel provides leak sealing capability, chemical & environmental resistance



Repairs are close fitting & can be applied in confined spaces

Lightweight repair kits are easy to transport & handle



FURMANITE

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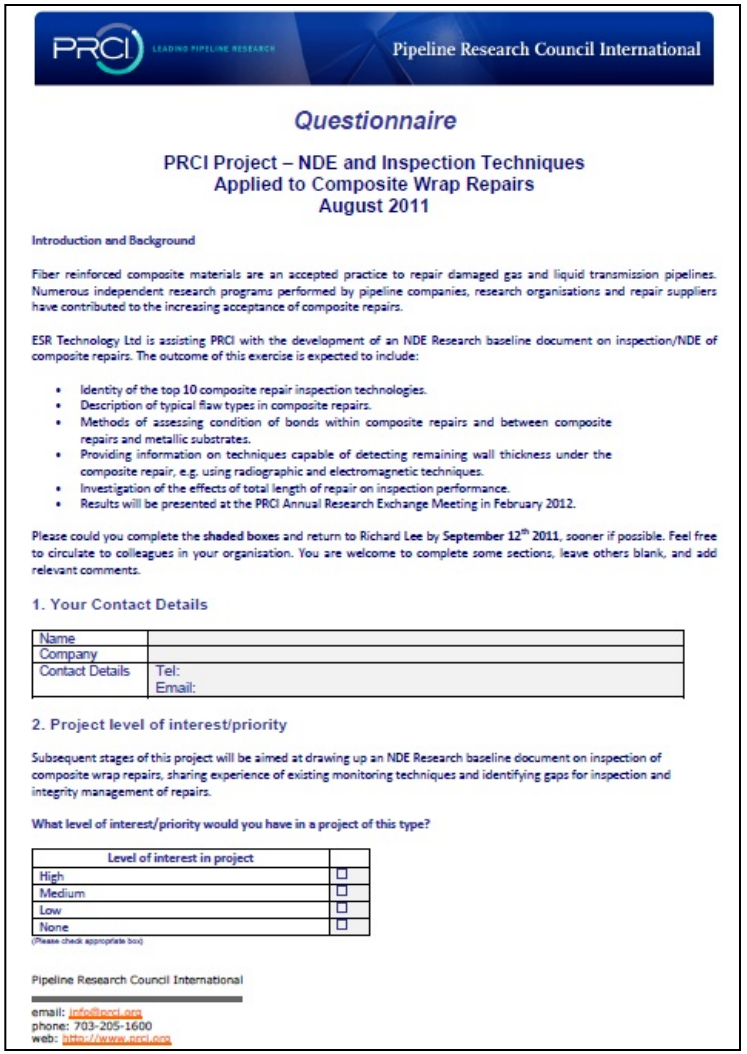
Questionnaire sent in August & October 2011



Pipeline Research Council International

Questionnaire

PRCI Project – NDE and Inspection Techniques
Applied to Composite Wrap Repairs
August 2011

Introduction and Background

Fiber reinforced composite materials are an accepted practice to repair damaged gas and liquid transmission pipelines. Numerous independent research programs performed by pipeline companies, research organisations and repair suppliers have contributed to the increasing acceptance of composite repairs.

ESR Technology Ltd is assisting PRCI with the development of an NDE Research baseline document on inspection/NDE of composite repairs. The outcome of this exercise is expected to include:

- Identity of the top 10 composite repair inspection technologies.
- Description of typical flaw types in composite repairs.
- Methods of assessing condition of bonds within composite repairs and between composite repairs and metallic substrates.
- Providing information on techniques capable of detecting remaining wall thickness under the composite repair, e.g. using radiographic and electromagnetic techniques.
- Investigation of the effects of total length of repair on inspection performance.
- Results will be presented at the PRCI Annual Research Exchange Meeting in February 2012.

Please could you complete the **shaded boxes** and return to Richard Lee by **September 12th 2011**, sooner if possible. Feel free to circulate to colleagues in your organisation. You are welcome to complete some sections, leave others blank, and add relevant comments.

1. Your Contact Details

Name	
Company	
Contact Details	Tel: Email:

2. Project level of interest/priority

Subsequent stages of this project will be aimed at drawing up an NDE Research baseline document on inspection of composite wrap repairs, sharing experience of existing monitoring techniques and identifying gaps for inspection and integrity management of repairs.

What level of interest/priority would you have in a project of this type?

Level of interest in project	
High	☐
Medium	☐
Low	☐
None	☐

(Please check appropriate box)

Pipeline Research Council International

email: info@prci.org
phone: 703-205-1600
web: http://www.prci.org

Information sought on :

- Level of interest in PRCI project.
- General experience of composite repairs applied to pipelines (and sub-sea).
- Significance of composite repair integrity.
- How many integrity issues in past 5 years ?
- Types of flaws requiring inspection.
- Number and locations of composite repairs on pipelines.
- What codes & standards are used?
- Do you operate a formal qualification process for composite repairs?
- How do you assess integrity?
- How are decisions reached to inspect composite repairs?
- Are composite repairs treated as temporary of permanent?
- What inspection techniques are carried out and what are the key issues ?
- What types of defects are of concern ?
- How are the results of the inspection analysed?
- Frequency of monitoring and inspection.
- Willingness to share experience with PRCI Review team.

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Questionnaires sent in August & October 2011

Information sought from PRCI Member contacts at :

Alliance Pipeline Ltd
Boardwalk Pipeline partners LP
Chevron Pipe Line Company
ConocoPhillips Pipeline Company
ExxonMobil Pipeline Company
Enbridge Pipelines
GDF Suez
Marathon Pipe Line LLC
Panhandle Energy
Petrobras
Saudi Aramco
TransGas Ltd
TOTAL S.A.
TransCanada Pipelines Ltd
TD Williamson, Inc

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Questionnaires sent in August & October 2011

Information sought from HOIS Member contacts at :

BP
Shell
Chevron
ConocoPhillips
Marathon Oil
Petrobras
Saudi Aramco
TOTAL
Talisman Energy
Statoil
GASCO
DOW
UK Health & Safety Executive
(13)

+ HOIS Category 2 Inspection Service Companies (22)

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Questionnaires sent in August & October 2011

Information also sought from Composite Repair Suppliers :

3X Engineering
www.3xeng.com
Prokem
www.prokem.org
Ferro Teknica
www.ferroteknica.com
Western Specialties
westernspecialtiesllc.com
IMG Composites
www.imgcomposites.co.uk
EMS Global
www.emsglobal.net
Neptune Research
www.neptuneresearch.com
Belzona
www.belzona.co.uk
PMI Denholm
www.denholm-pipecare.com
Air Logistics
airlog.com

Armorplate
armorplateinc.com
Citadel Technologies
www.cittech.com
Comptek Composites
comptekcomposites.com
Pipe Repair
www.piperepair.net
Pipe Stream
www.pipestream.com
Wrap Master
www.wrapmaster.us
Furmanite
www.furmanite.com
TechCorr
www.techcorr.com
ClockSpring
www.clockspring.com
Walker Technical
www.wtr.uk.com

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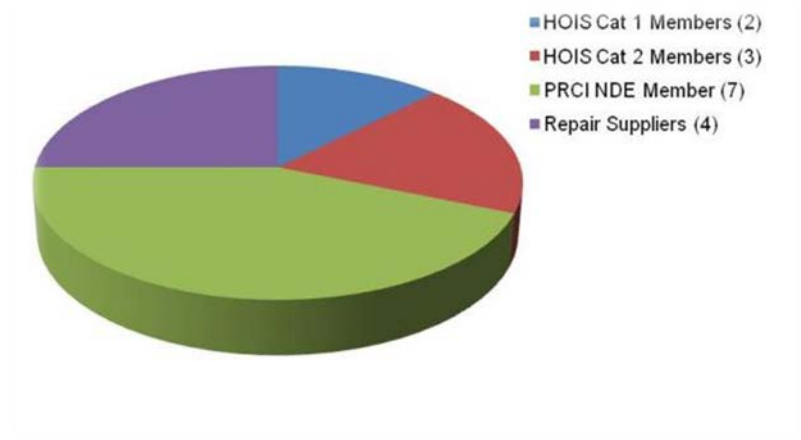
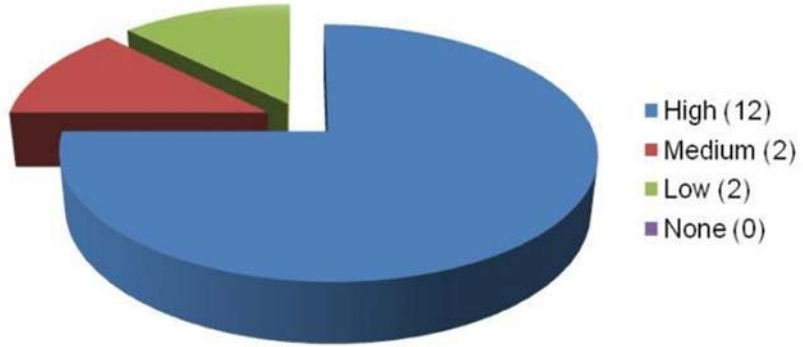
Questionnaire Responses - 1

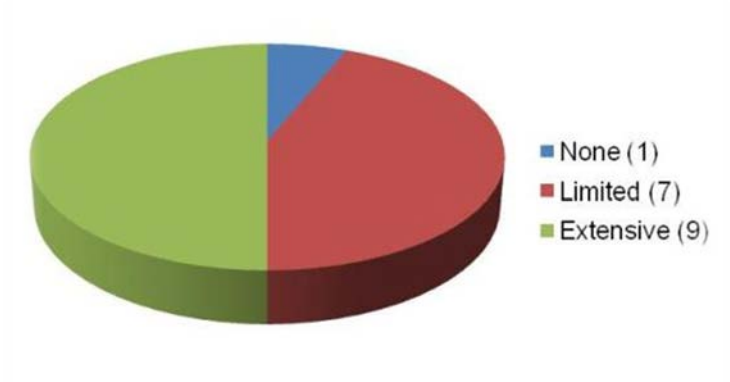
Replies recorded (16) – 22% return rate



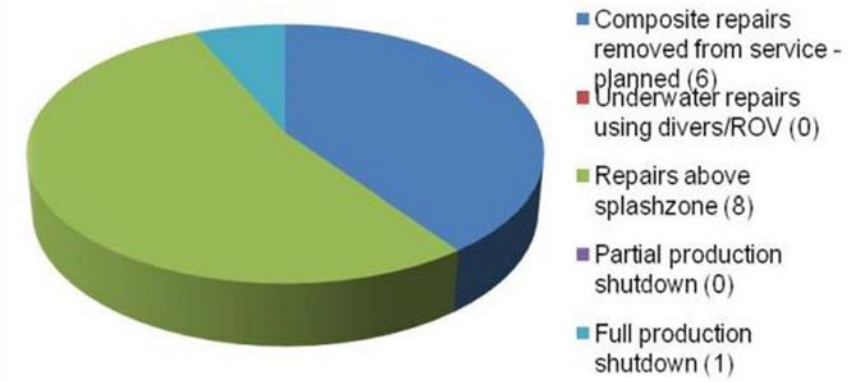
Level of Interest in NDE of Composite Wrap Repairs



Experience in composite wrap repairs applied to pipelines



Integrity issues in past 5 years with composite wrap repairs applied to pipelines



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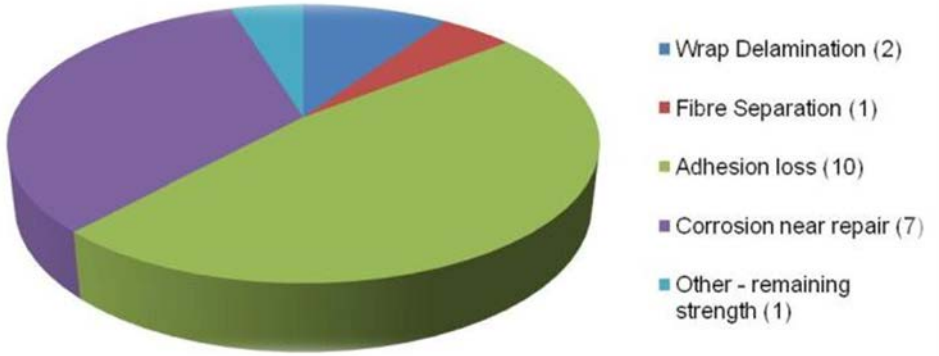
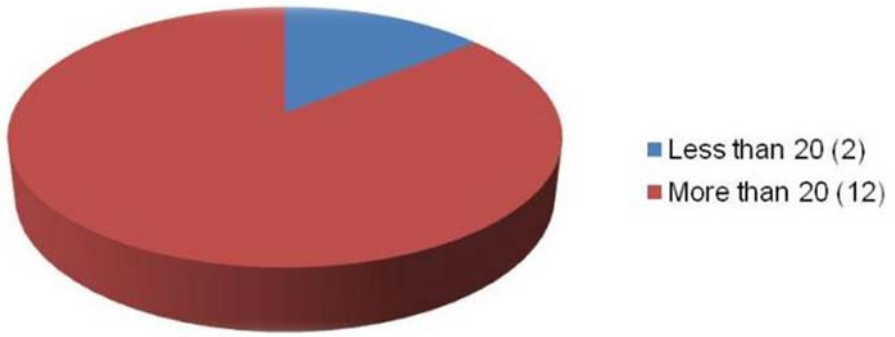
Questionnaire Responses - 2

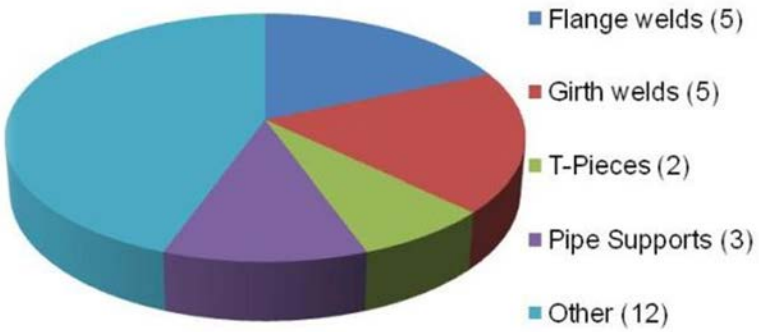
Types of flaws to inspect applied to pipelines



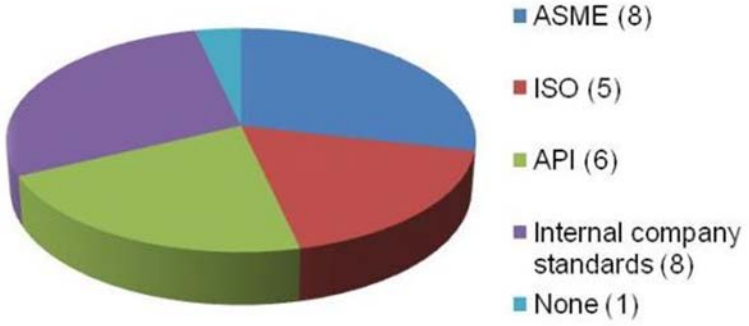
Number of repairs applied to pipelines



Locations of repairs applied to pipelines



Codes & Standards used for repairs applied to pipelines



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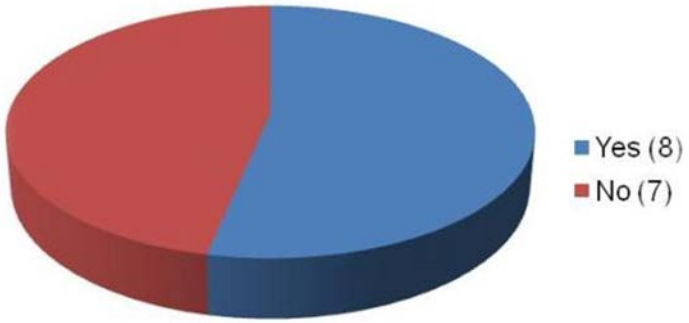
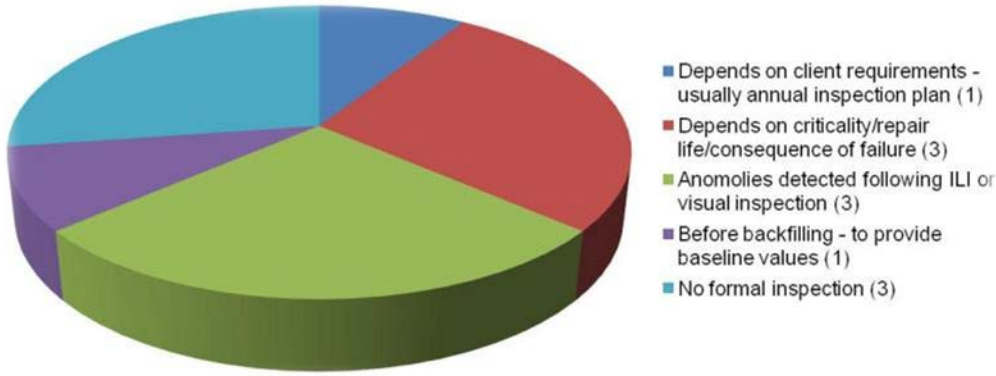
Questionnaire Responses - 3

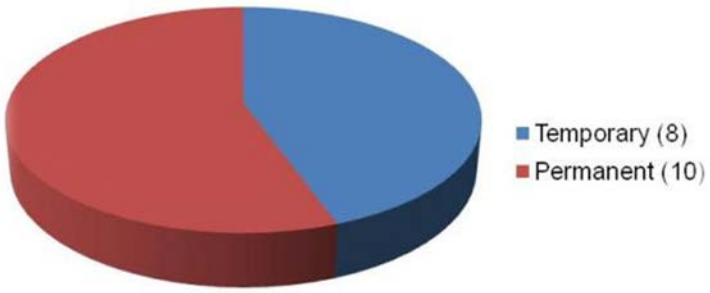
Formal qualification/approval of repairs applied to pipelines



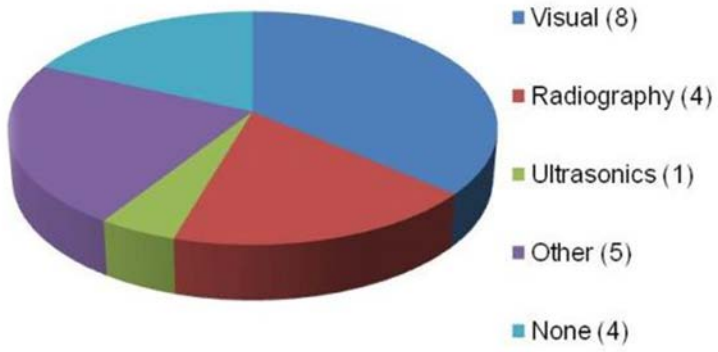
When to inspect repairs applied to pipelines



Are repairs treated as temporary or permanent applied to pipelines ?



Inspection methods used applied to pipelines



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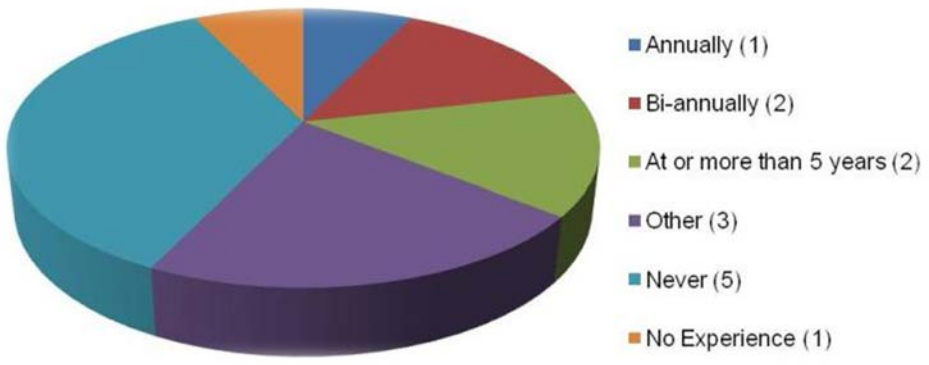
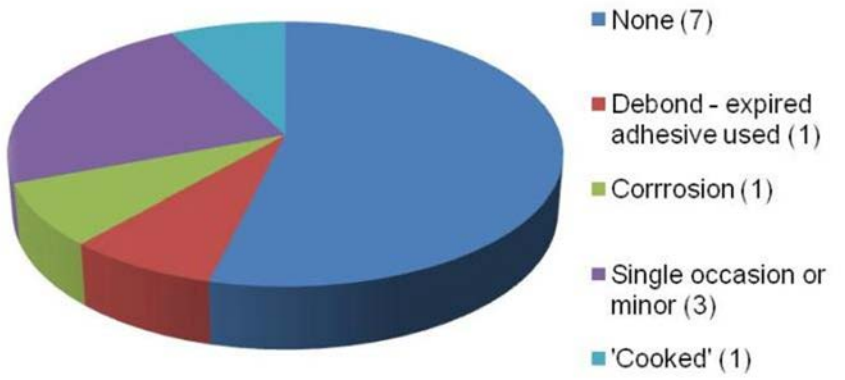
Questionnaire Responses - 4

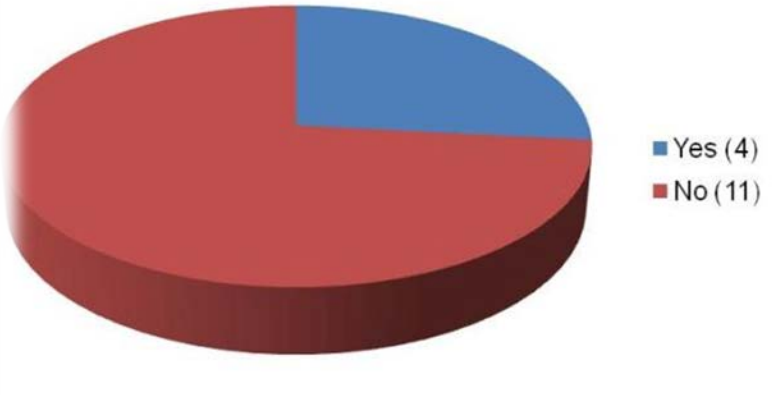
Inspection frequency applied to pipelines



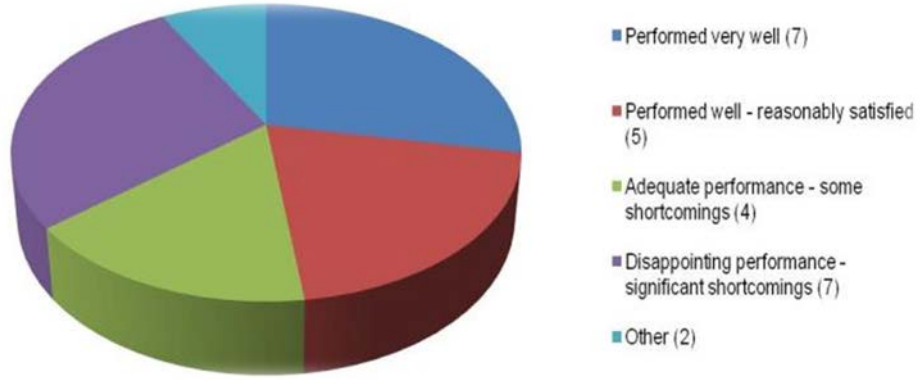
How many occasions in past 5 years have you encountered integrity issues with composite wrap repairs ?



Have you experienced a composite wrap repair failure ?



General experience with inspection of a composite wrap repair



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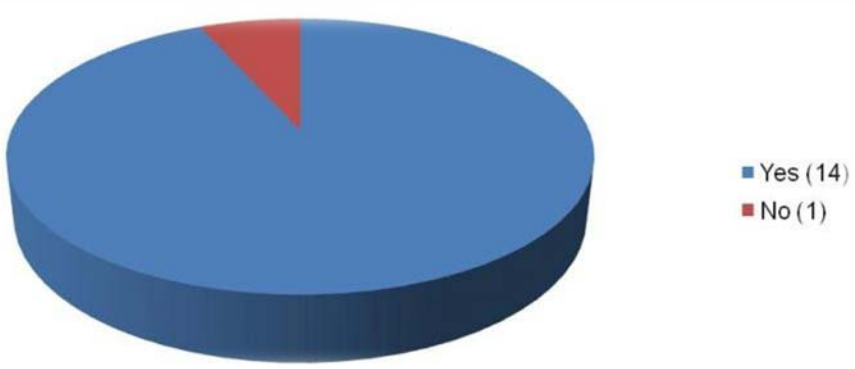
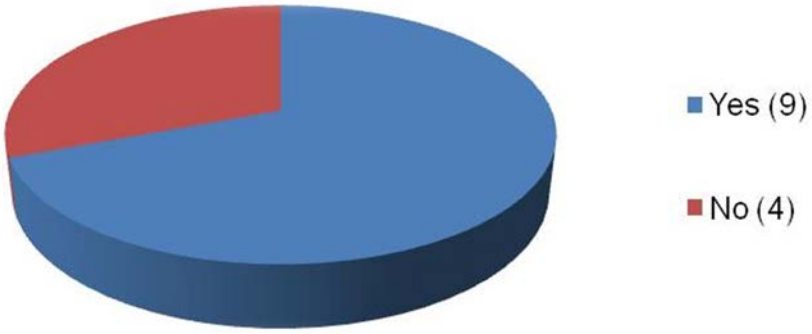
Questionnaire Responses - 5

Are you willing to share experience with PRCI Review Team ?



Can you provide further information, e.g. in-house standards on inspection with PRCI Review Team ?



'Most critical aspect of composite repairs is the installation of the composite.

As an operator, I would like to have an NDT/Inspection method available that would verify the installation of the composite was done properly and that the composite would likely be a permanent repair before the location is backfilled.

Additionally, I would like to have an NDT method (it might be the same method) to use in future years to verify the repair is still bonded to the pipe and that the composite itself has not degraded.'

Pipeline Operator

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What are the applicable standards?

- **ISO/TS 24817**
  - International Standard/Technical Specification – composite repairs for pipework
- **ASME PCC-2**
  - Article 4.1, Non-metallic composite repair systems for pipelines and pipework: low risk applications.
  - Article 4.2, Non-metallic composite repair systems for pipelines and pipework: high risk applications.

- Both standards are published (and under revision).
- No major differences in the technical details.
- New Work Item Proposal accepted by ISO TC67/SC6 (led by Simon Frost, Walker Technical) via OGP/ISO route. Working Draft in progress.
- Revision of ISO/TS underway – next meeting in Aberdeen October 2012.

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International Standard ISO/TS 24817

The content of ISO/TS 24817 includes details on;

Qualification requirements; tests that suppliers are required to comply to the standard

Design details; how to design a repair

Installation guidance; what are the critical issues, e.g. surface preparation and applicator training requirements

Monitoring guidance; how to inspect the repair system

No other reference standard or guideline is required to complete the composite repair application.

The standard should be used in conjunction with any in-house procedures or guidelines on composite repairs

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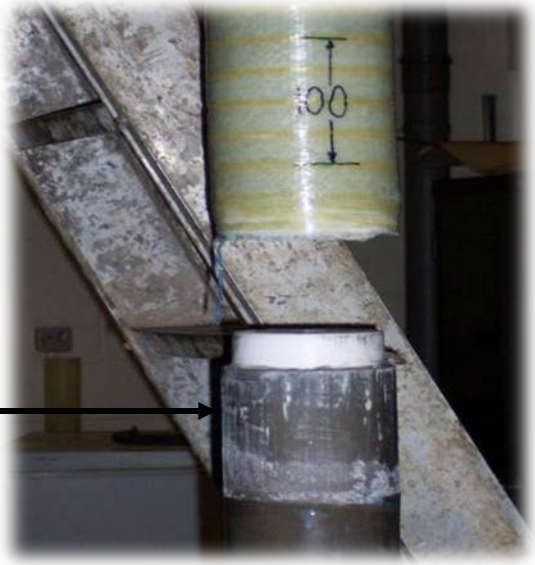
How do composite repairs fail?

- The failure occurs at the interface between the metallic substrate and the composite laminate
- Failure is benign, a weepage of contents from the edge of the repair

Internal pressure of repair on pipe bend 30 mm diameter through-wall defect

Axial load – fully circumferential defect – failure at the interface



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Inspection – what to inspect?

What to inspect for;

- Growth of internal defects in substrate underlying the repair
- Delamination at the interface between the composite repair and the substrate
- Degradation of the composite repair (less of an issue)

Where to inspect;

- Commonly all three types of defects need to be inspected from above the repair (access axially and internally often restricted)

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How to inspect repairs?

Internal defect growth in steel substrate:

- Electromagnetic techniques, e.g. low frequency or pulsed eddy current for general wall loss
- Gamma- and X-rays (using conventional film, CR or DR equipment)

Interfacial delamination:

- Microwaves
- Mechanical impedance (electronic coin tappers)
- Digital X-rays (further assessment of these techniques required)
- Laser shearography
- Ultrasonics (some practical limitations)

Composite repair:

- Visual inspection
- Monitor strain (conventional strain gauges or fibre optic sensors)
- Hydrotesting

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Inspection – which techniques?

Many techniques are available - Most are commercially available systems

- **Acoustic emission** (stress wave emission, Amplitude, Energy or Rate)
- **Computed Tomography** (reconstruction of 3D slices)
- **Crack growth monitoring** (Gauges & video camera)
- **Digital Image Correlation** (DIC)
- **Electromagnetic** (Pulsed Eddy Currents and SLOFEC)
- **In Line Inspection (ILI) Tools** (NACE RP 0102 & API 1163)
- **Laser shearography**, holography & Interferometry (Geometric and Moiré)
- **Leak detection**
- **Microwave Inspection** (10 GHz and 24 GHz for dielectrics)
- **Sonic vibration** and Mechanical impedance (electronic tappers)
- **Strain monitoring** (gauges, digital image correlation, fibre optics)
- **Thermography** (Active & Passive)
- **Ultrasonics** (Conventional, Advanced, Long Range, M-Skip, ART - Acoustic Resonance Technology)
- **Visual/Video/CCTV** – Enhanced
- **X- and Gamma- Radiography** (Film and Digital)

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Some examples of inspection of composite repairs

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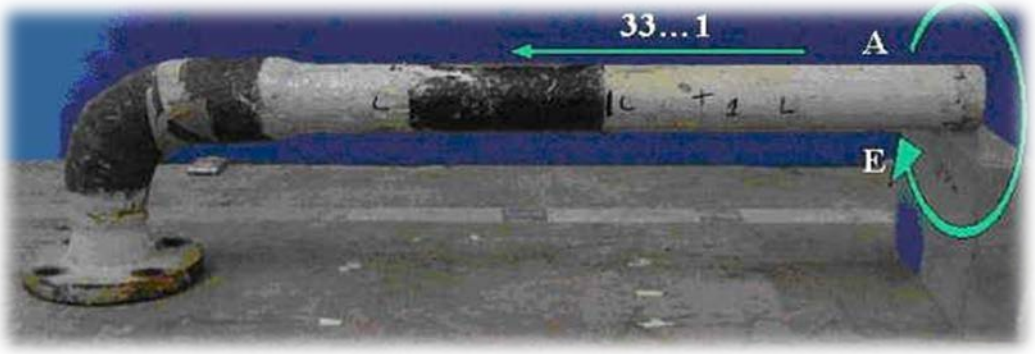
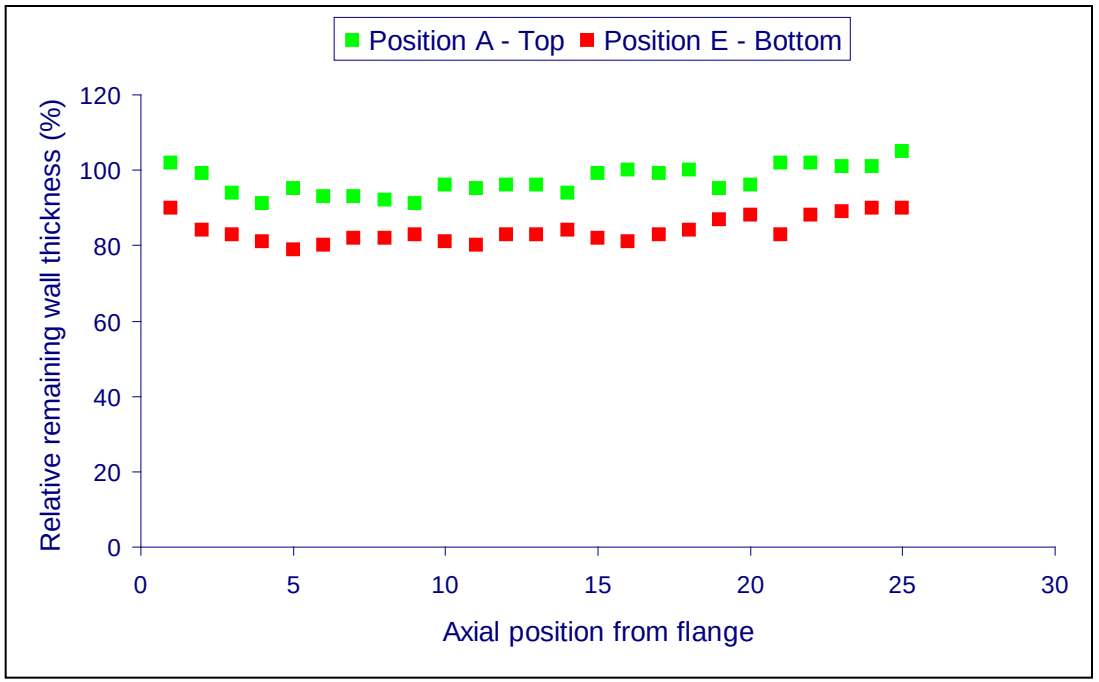
Electromagnetic





PEC (pulsed eddy current) trial on glycol drain system

Underlying remaining wall thickness of steel pipe readily detected.

Resolution limited – defects of diameter 10 mm or less cannot be detected

SLOFEC not trialled in this case but is a possible alternative technique.

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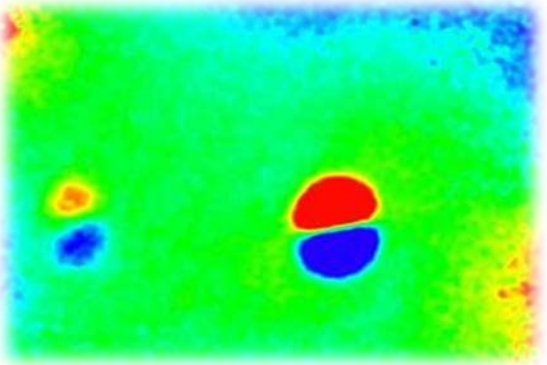
Laser Shearography



Laser Optical Engineering Ltd

DANTEC DYNAMICS

COMPOSITE INSPECTION
Advanced Non Destructive Testing

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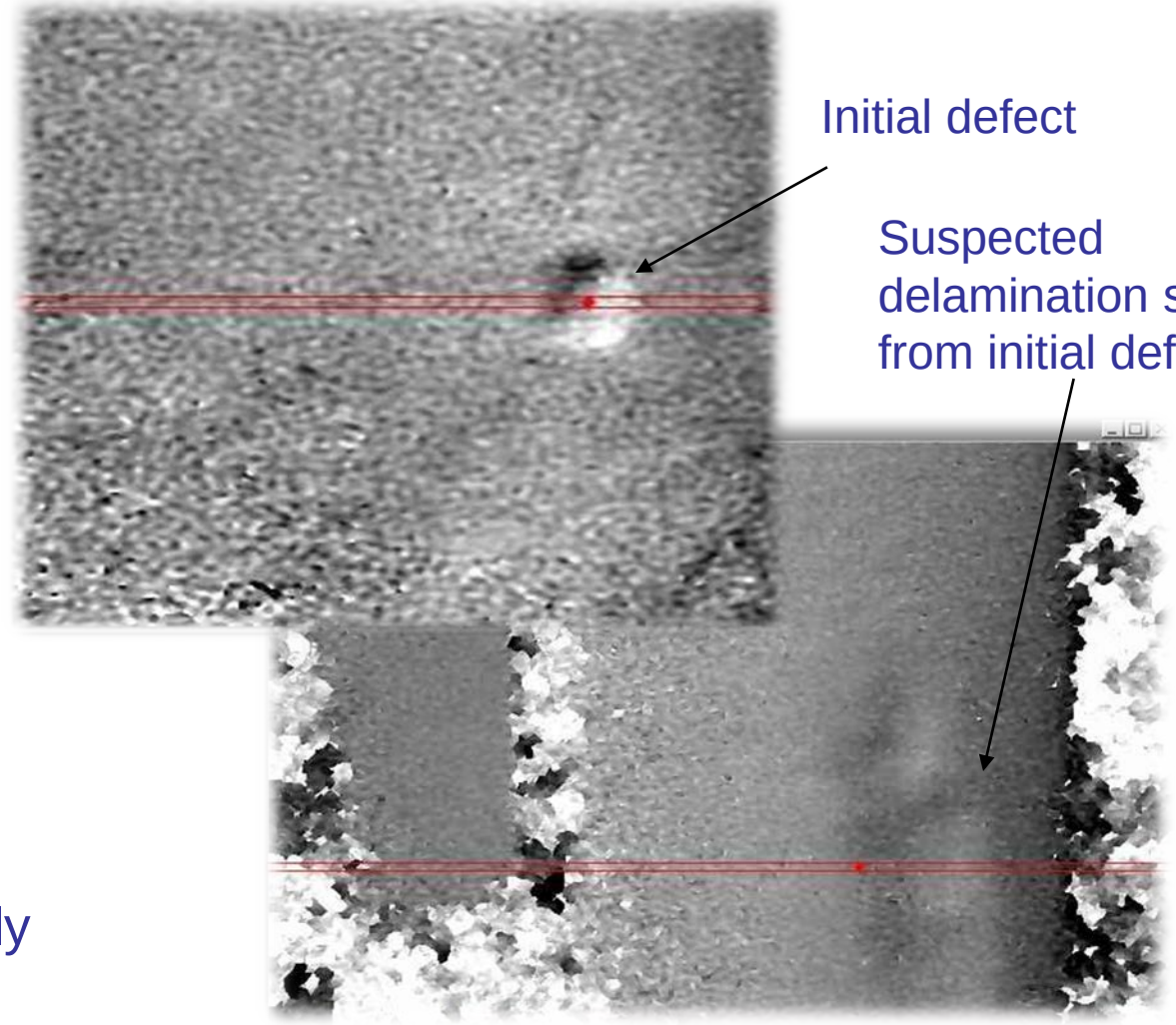
Laser Shearography



Laser shearography trial

Interfacial delamination detected in some trials only

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Composite wrapped pipes

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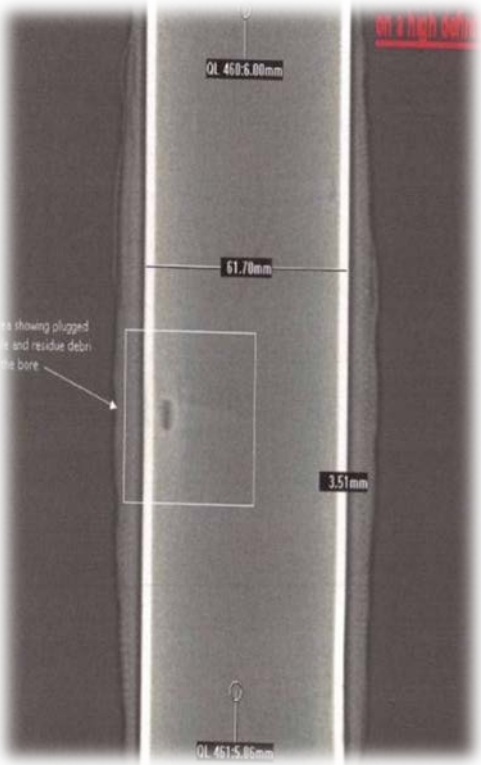
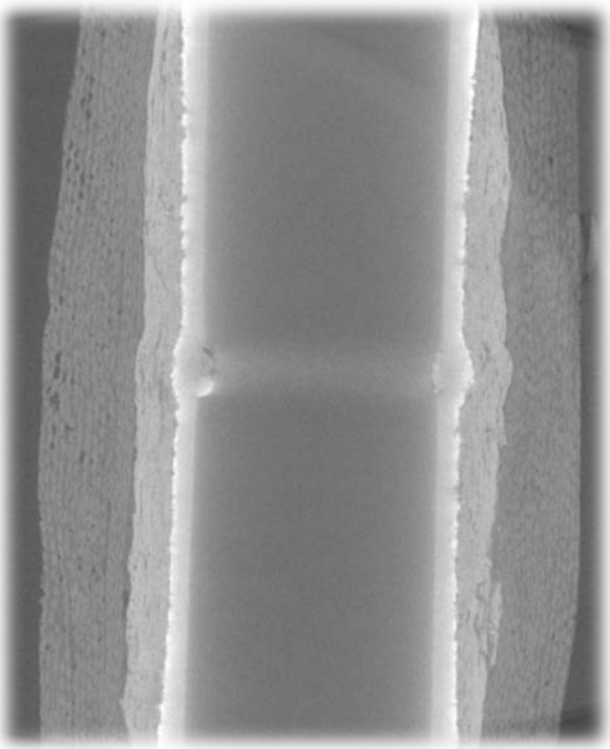
Computed/Digital Radiography

Example of use of digital radiography showing underlying defects and state of the composite repair





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Microwave Inspection - Pipe wrap repair

Evisive Microwave Trials IMG 6” Repair

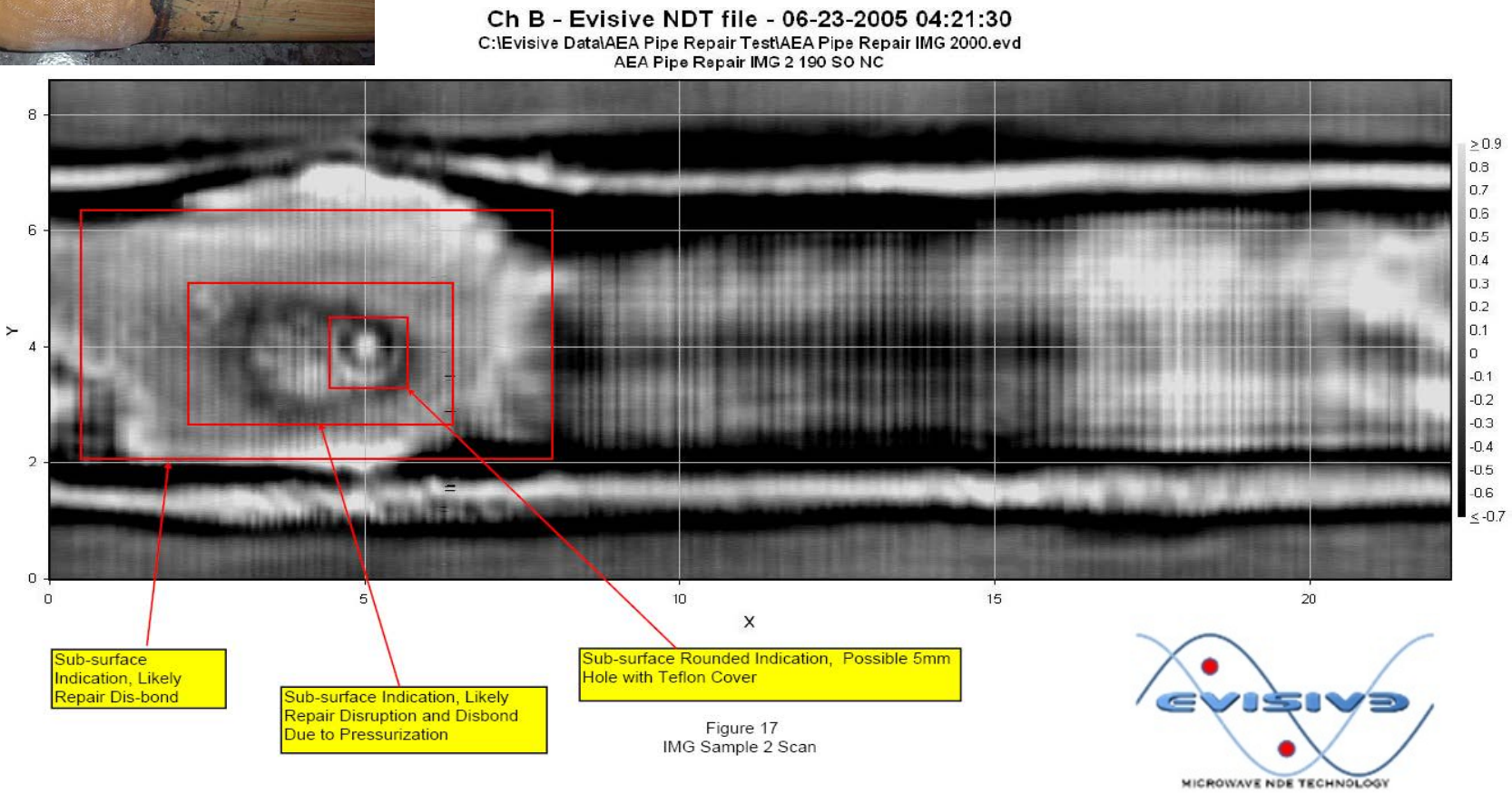

Figure 17
IMG Sample 2 Scan

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Microwave Inspection

Evisive Microwave Trials on ClockSpring 6” pipe repair

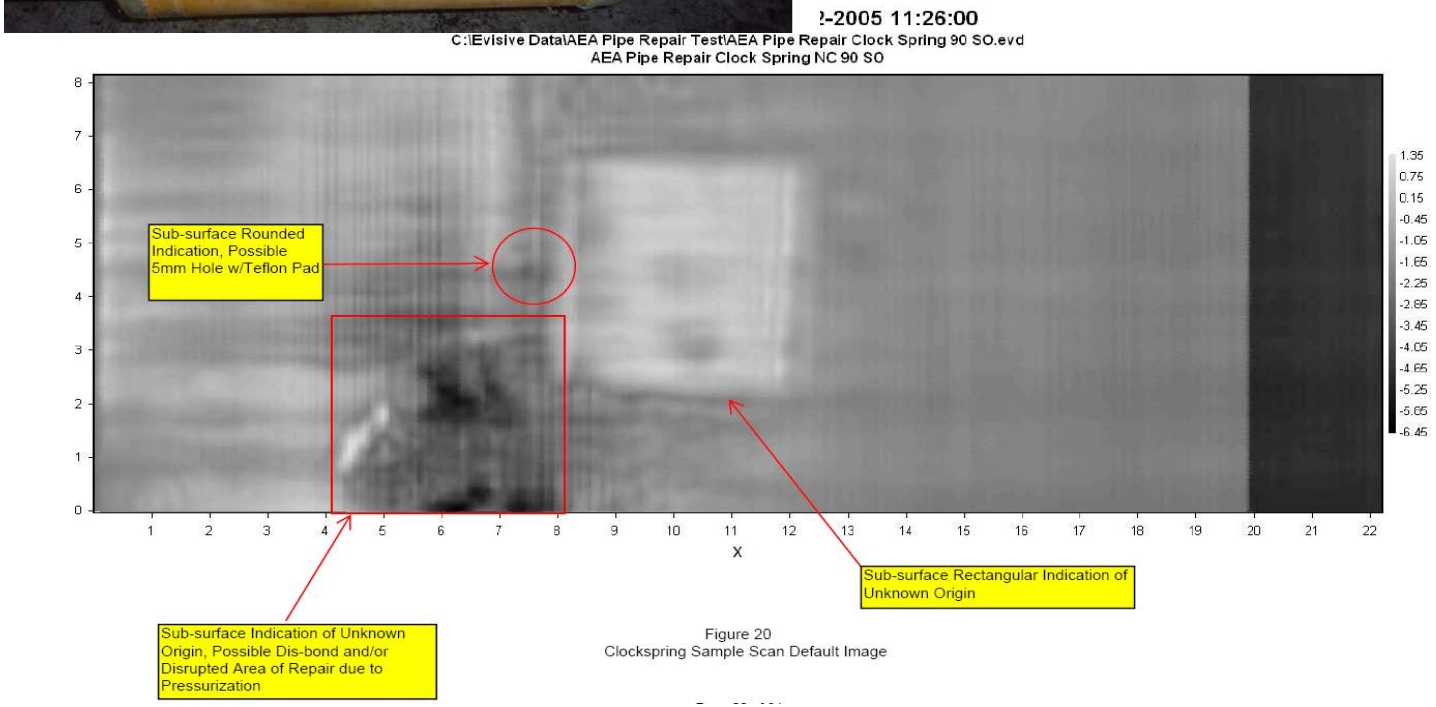
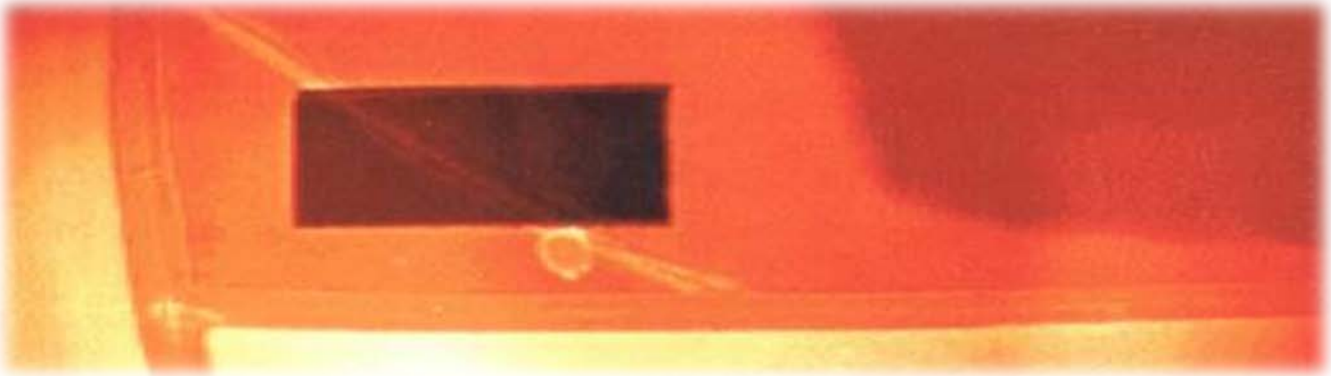


Figure 20
Clockspring Sample Scan Default Image

Thermography



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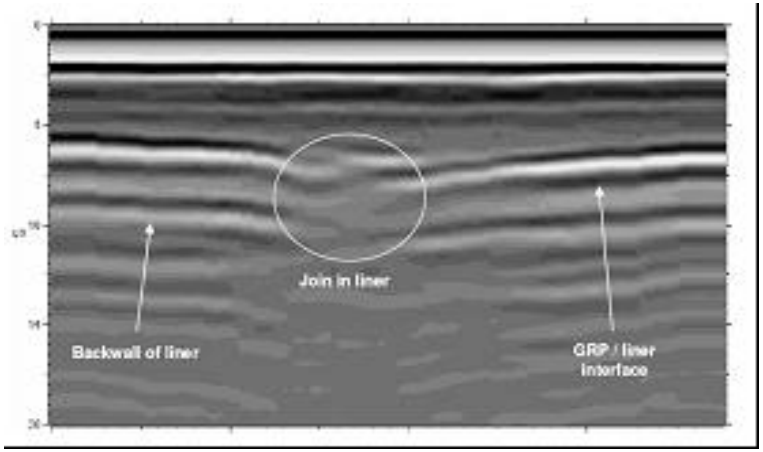
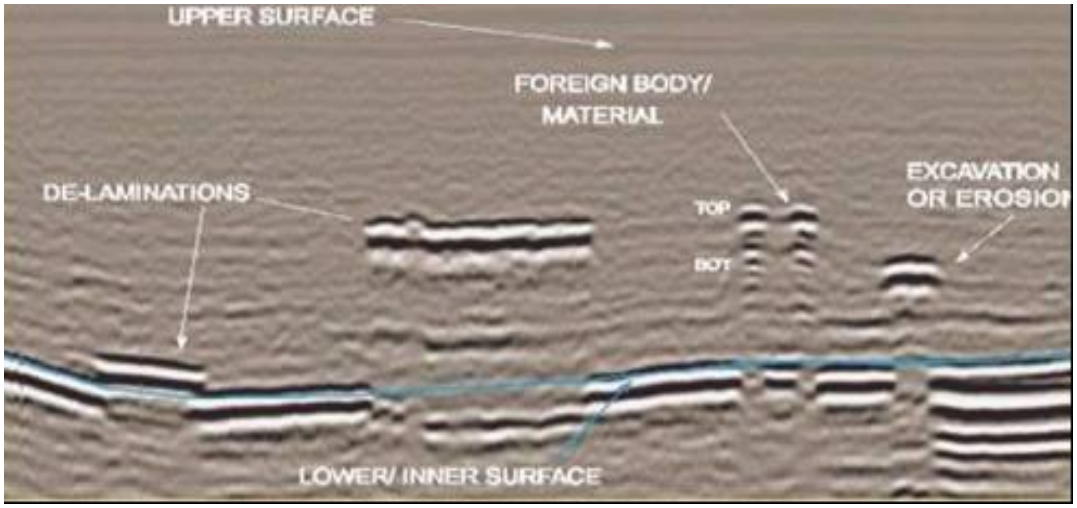
Ultrasonics (B-Scan, M-Skip and TOFD)





Pipe wall loss through severe chemical attack

Erosion and wall loss, liner damage

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Inspection of delaminations within adhesively bonded connections

- Techniques used;
  - Microwaves
  - X-rays
  - Mechanical impedance

- Comments
  - Overall probability of detection of kissing bonds (lack of adhesion) was low.
  - Microwaves had some success but further developments may be required.

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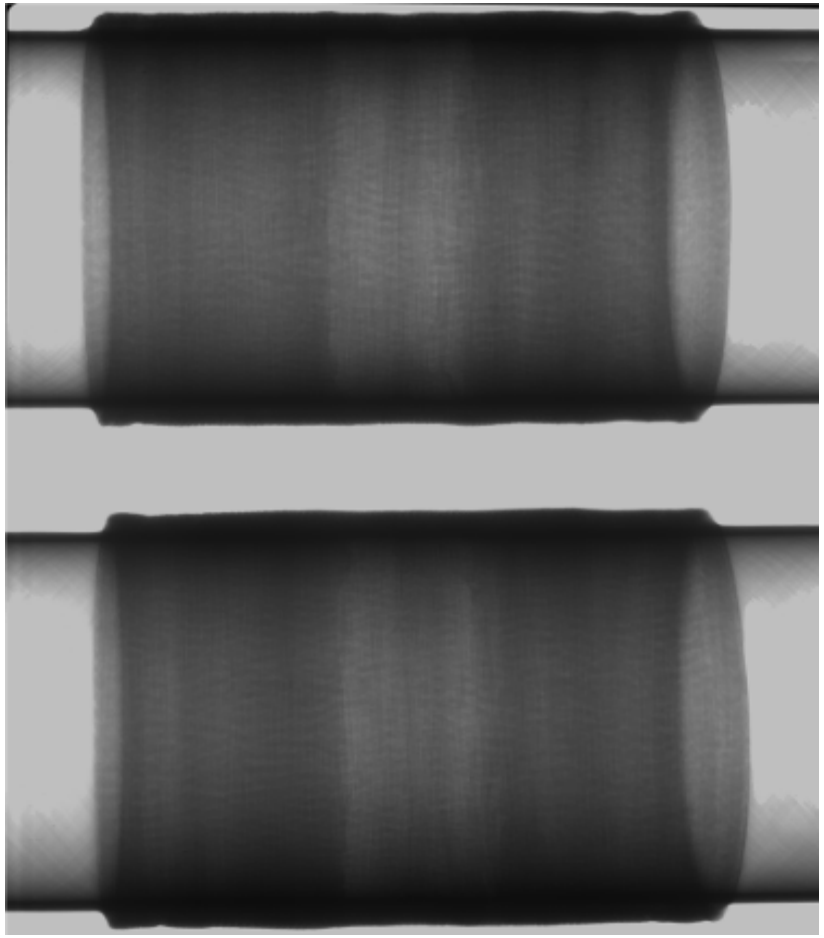
Inspection of delaminations within adhesively bonded connections



X-rays (Digital imaging)

- Trials were performed on connections with fully circumferential (‘kissing bond’) defects of size 20%, 40% and 60% of available bonded area
- ‘Kissing bond’ defects could not be detected in any of the tests

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Case Study – Piping repair

WTR Technowrap system

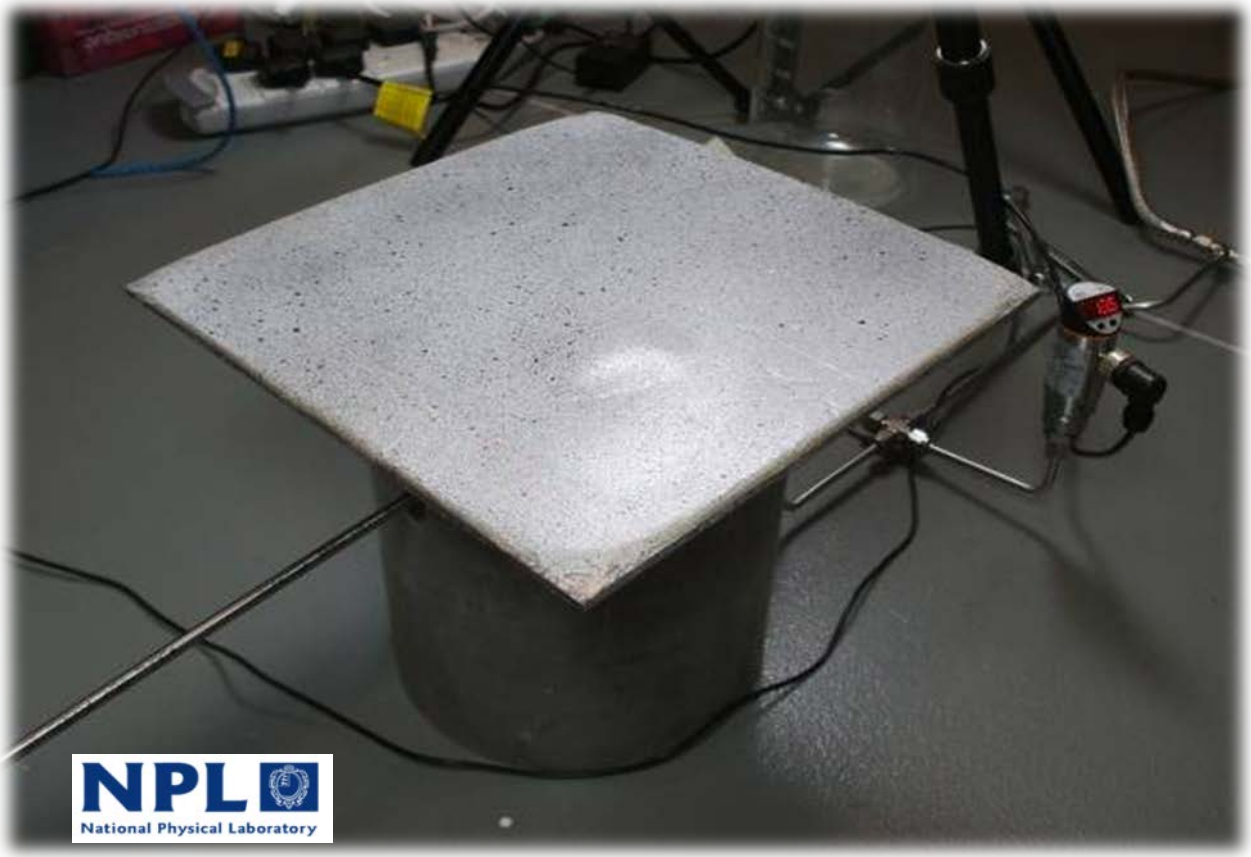
Multi-axial glass/ epoxy panel bonded to steel plate

3 panels tested

- Hand prep
- No Primer
- With primer

© ESR Technology Ltd

Case Study – Piping repair



Tested at NPL in UK

Connected to hand pressure pump (Hi-Force) using pressure adapter.

Digital Image Correlation (DIC) equipment used LAVision DAVIS 7.4 software

www.lavision.de

Panel #2

Blister formed at 100 bar before weeping at 150 bar.

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AE Monitoring

Report – FT5373 - AE monitoring of plate blow-off tests at NPL for Imagine Project.doc

PHYSICAL ACOUSTICS LIMITED

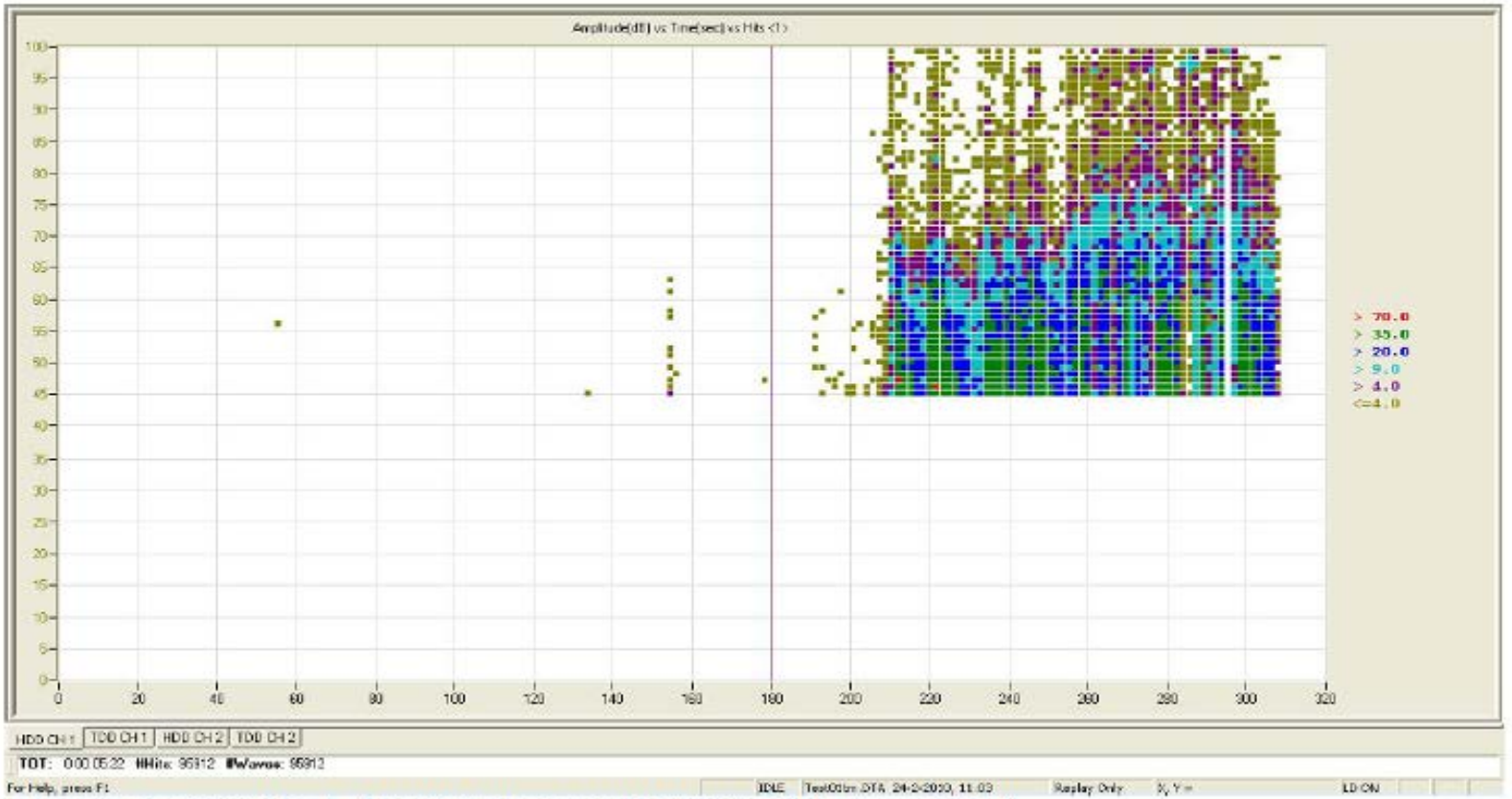

Figure 2: Sample 1 Amplitude results from CH1 (on steel)

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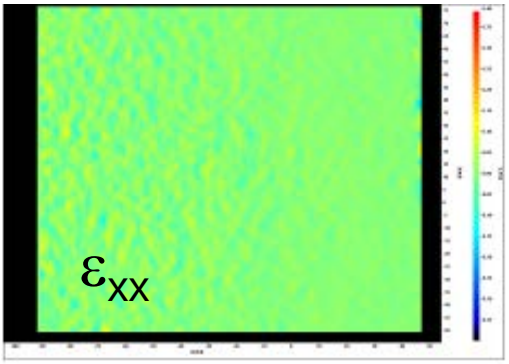
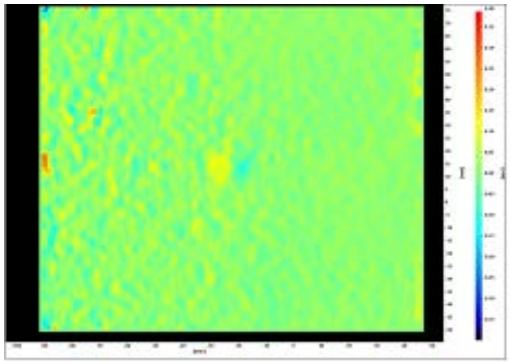
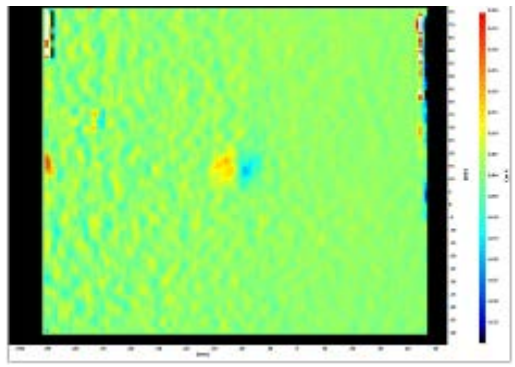
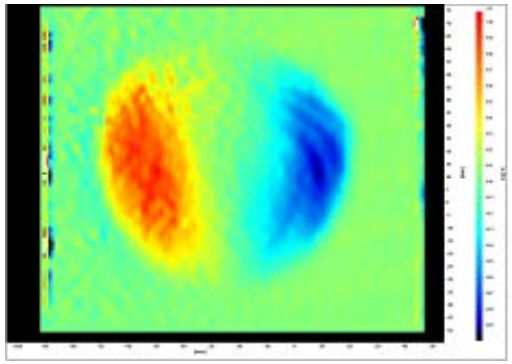
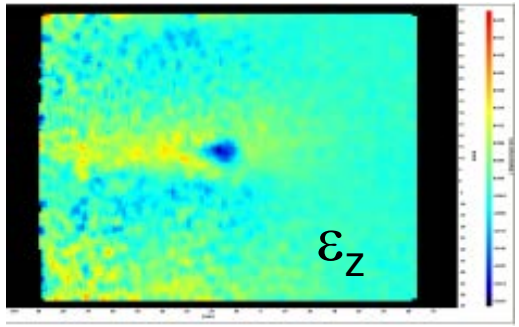
Pipe repair - Digital Image Correlation

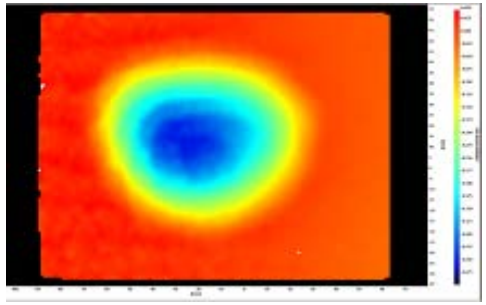


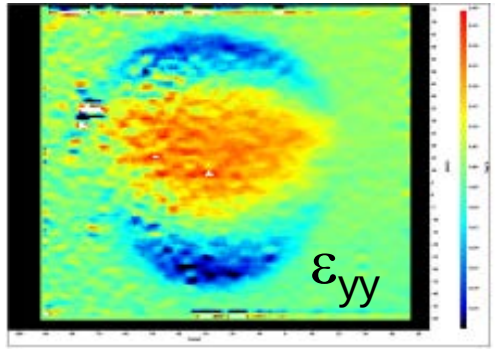












Selected DIC images for ε_{xx}, ε_{yy} and ε_{z}

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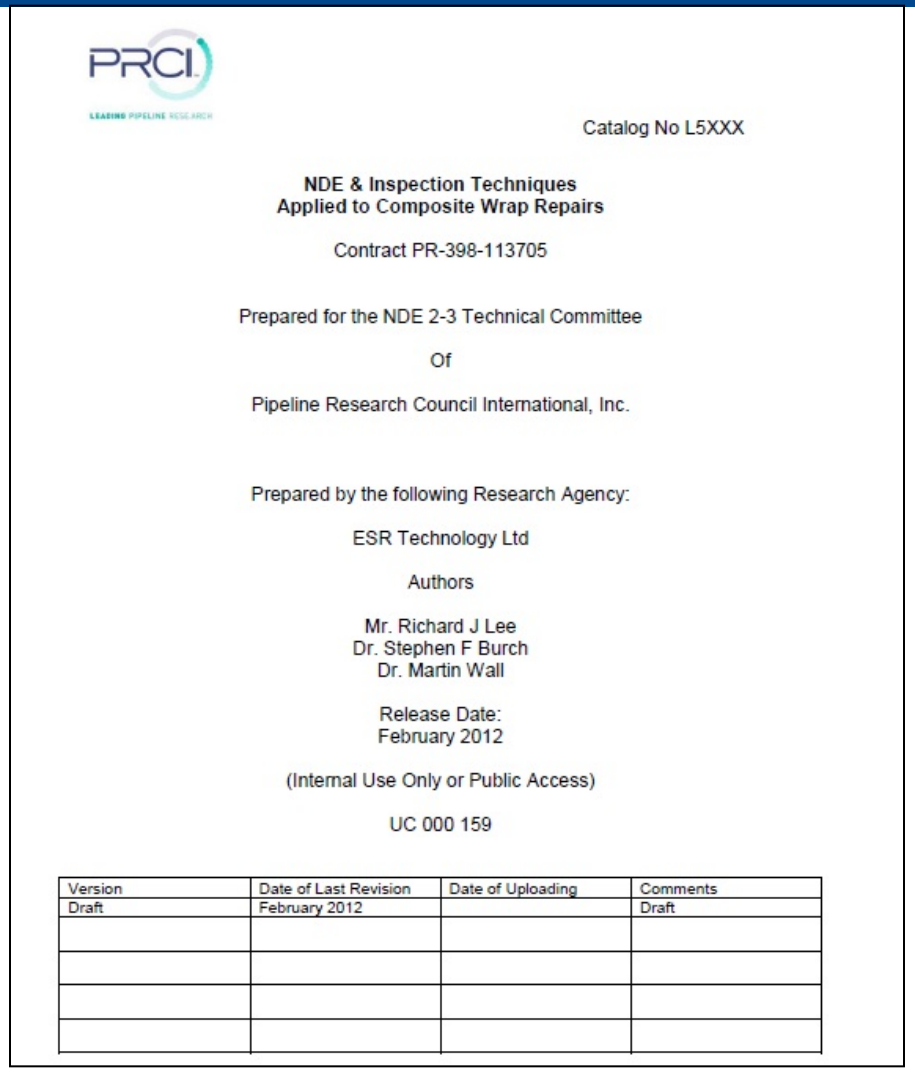
PRCI Baseline document



PRCI

Catalog No L5XXX

NDE & Inspection Techniques Applied to Composite Wrap Repairs

Contract PR-398-113705

Prepared for the NDE 2-3 Technical Committee

Of

Pipeline Research Council International, Inc.

Prepared by the following Research Agency:

ESR Technology Ltd

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Release Date:
February 2012

(Internal Use Only or Public Access)

UC 000 159

Version	Date of Last Revision	Date of Uploading	Comments
Draft	February 2012		Draft

PRCI baseline document on inspection/NDE of composite repairs.

Publication/release date – July 2012.

- **INTRODUCTION**
- **SCOPE**
- **REQUIREMENTS**
- **INSPECTION APPROACH**
- **ALLOWABLE DEFECTS**
- **REPAIR OF DEFECTS**
- **MAINTENANCE AND REPLACEMENT STRATEGY**
- **INSPECTION METHODS**
- **RECOMMENDED NDT FOR OVERWRAP REPAIRS**
- **INSPECTION TECHNIQUE ASSESSMENT**
- **CONCLUSIONS AND RECOMMENDATIONS**
- **BIBLIOGRAPHY**
- **APPENDICES**
  - Appendix 1 - Optical methods
  - Appendix 2 - Thermographic methods
  - Appendix 3 - Radiographic methods
  - Appendix 4 - Acoustic methods
  - Appendix 5 - Magnetic methods
  - Appendix 6 - Ultrasound methods
  - Appendix 7 - Eddy current methods
  - Appendix 8 - Visual methods
  - Appendix 9 - Penetrant methods

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Comments on inspection of composites

- Composite materials are being used in many safety critical applications, the most obvious examples are in aerospace and wind energy (e.g. Airbus A350-XWB, Boeing Dreamliner 787).
- Large structures pose particular difficulties for inspection.
- Oil & Gas industry are adopting FRP pipes and composite repairs.
- The Civil Industry are using composites for some new build and bridge strengthening.
- Inspection tools are available but the nature of composites still present unique challenges compared to metals. Recent developments have included large area, non contact inspection techniques such as microwaves, shearography and thermography.
- Potential strategies include fast screening, global methods, monitoring or application of risk-based inspection methods – depending on how much is known on type and location of damage and integrity requirements.
- Ultrasonic inspection using phased arrays mounted inside roller probes are being used for in service inspection.

‘You get what you inspect, not what you expect’

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Status of Composite Repairs

- Standard documentation is now in place for composite repairs
- Composite repairs are an engineered solution – mostly topside but some limited experience sub-sea.
- The qualified repair consists on the repair material, the surface preparation procedure and the substrate
- Inspection of the substrate underneath the repair can be achieved – interfacial delaminations are still problematic
- Current Best Practice is being developed. It is expected that advances in in-service inspection and condition monitoring will continue.

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UK Composite Networks

National Composites Centre leads the coordination of technology transfer across UK regions. www.nationalcompositescentre.co.uk. Work is undertaken in conjunction with the NCN who are part of the Materials Knowledge Transfer Network. The network maximises the impact of support for rapid manufacturing technologies and cross-sectorial coverage, as well as strengthening the UK's composites supply chain.

National Composites Network is a Knowledge Transfer Network jointly funded by UK government and industry embracing the UK Composites industry and its supply chain. www.ncn-uk.co.uk

Composites UK is the representative body of the UK composites industry. Their aim is to promote the industry so that it may continue to grow and participate in the increasingly competitive world of global composite production. Their mission is to enhance and promote the safe and effective use of composites. www.compositesuk.co.uk/

NetComposites is a global research, consultancy and online media company, creating and using innovative technologies to advance the composites industry. The web portal www.netcomposites.com contains over 10,000 pages of information for composites professionals, including a guide to composites, latest industry news, calendar, glossary, industry directory and the world's largest online stores for composites information. A free newsletter is sent directly to well over 16,000 composites professionals in 76 countries.

NWCC The Northwest Composites Centre was established by the Universities of Bolton, Lancaster, Liverpool and Manchester to create a centre of international scientific reputation to the benefit of industry. www.futurecomposites.org.uk/

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EU Composite Networks

CO-PATCH – Composite Repair for Marine and Civil Engineering Infrastructure Applications.
www.co-patch.com

Stakeholders Forum II held in Genoa, Italy in January 2012. Final Meeting in London end of 2012.

Definition of an effective repair/reinforcement method for large steel structures with defects and demonstrate that composite patch repairs or reinforcements can be environmentally stable and that they can be used as permanent repair measures.

Civil sector: focus on metallic bridges – 3 cases selected

Marine sector: focus on defects found on-board Bulk Carriers, Containerships and Oil Tankers – 5 cases selected.

Repairs in both the marine and civil applications could be a viable, cost effective and permanent alternative to traditional repair methods such as cropping and renewing of steel.

Key Challenges:

- To get class approval for the patch repair, currently it stands at “temporary” and we hope by the end of the project it will “permanent”
- Inspection technology
- Surface preparation (grit blasting still remains the best option)
- Long term performance, fire protection

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EU Composite Networks

CO-PATCH – Composite Repair for Marine and Civil Engineering Infrastructure Applications.
www.co-patch.com

NDT of Composite Patches

Crack in metal	OptFib, UltraS, xRay,
Corrosion in metal	UltraS
Adhesive	OptFib
Laminate	OptFib, UltraS

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Norwegian University of Science and Technology (NTNU) Trondheim. andreas.echtermeyer@ntnu.no

Dr. Elena Rodriguez Senin – Aimen Technology Centre, Spain. www.aimen.es

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Acknowledgements

Mark Piazza, PRCI, Programme Manager
Steve Burch & Martin Wall, HOIS & National NDT Centre (NNDTC)

Composite Repair Suppliers:

Simon Frost, Walker Technical (ISO 24817 Chairman).
Belzona, Babcock Marine, Furmanite, IMG, ClockSpring and others.
Inspection Service Companies (including HOIS Cat 2 members)

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PRCI Project NDE 2-3
NDE & Inspection Techniques Applied to Composite Wrap Repairs

PRCI Project No. PR-398-113705

Richard Lee, Steve Burch

& Martin Wall

ESR Technology, UK

2nd Annual Composite Repair Users Group

Conference & Exhibition Sept 7 2012, Houston, TX (Norris Conference Center)

PRCI
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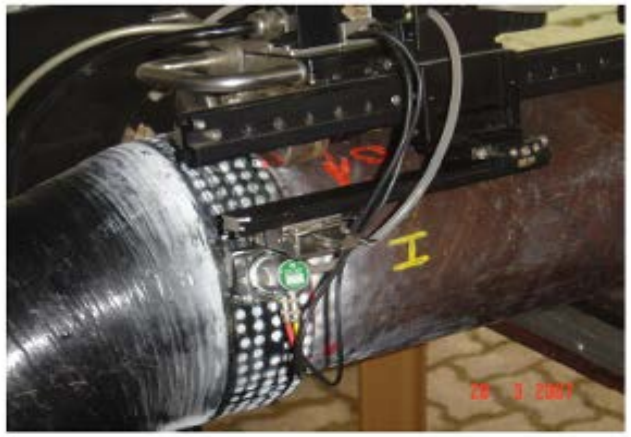
Example of HOIS Good Practice Guide



HOIS good practice guide on in-service inspection of offshore composite components

HOIS09GP1 Issue1

A Report prepared for HOIS

by

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martin.wall@esrtechnology.com
richard.lee@esrtechnology.com

January 2010

HOIS

- Produced by the HOIS Joint Industry Project
- HOIS good practice guide on in-service inspection of composite components
- Updates ISO-14692 and NORSOK M-622 guidance documents.
- Provides some guidance on strategy, technique selection and more specialised NDE techniques.
- Flowcharts for manufacturing and in-service inspections (update of NORSOK flowcharts).
- More practical information on application of NDE methods than existing standards (NORSOK M-622, ISO)
- Public version available from HOIS website www.hois2000.com

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