Pertanika J. Sci. & Technol. 28 (S1): 151 - 158 (2020)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Composite Repairs Integrity Assessment: An Overview of Inspection Techniques

Siti Haslina Mohd Ramli[1]*, Rosman Arifin[2] and Hambali Chik[3]

[1]*Materials, Corrosion and Inspection Group, Infrastructure Department, Engineering Division, Group Technical Solutions, Project Delivery & Technology, PETRONAS, 50088 Kuala Lumpur, Malaysia*
[2]*Pipeline Group, Infrastructure Department, Engineering Division, Group Technical Solutions, Project Delivery & Technology, PETRONAS, 50088 Kuala Lumpur, Malaysia*
[3]*Materials, Corrosion and Inspection Group, Infrastructure Department, Engineering Division, Group Technical Solutions, Project Delivery & Technology, PETRONAS, 50088 Kuala Lumpur, Malaysia*

ABSTRACT

Composite repairs have been increasingly applied for maintenance and rehabilitation of piping, pipelines and vessels in the oil and gas industry, thus there is a growing need to monitor their in-service integrity, repair lifetime extension and prevent loss of containment of the product. There are many challenges of inspecting composite repairs including accessibility, inhomogeneous and anisotropic structure of composites, probability of detection, lack of adequate standards and diversity of composite materials amongst others. The current practice for inspection and monitoring of composites repair on oil and gas piping and pipelines is usually conducted based on International Standards Organisation (ISO) 24817 whereby visual inspection is generally performed to observe any irregularities on the surface like discolouration, cracks, chalking and blistering. This will usually be followed through with a coin tap test and Barcol hardness testing. Upon any findings of anomalies, further investigation is then performed using advance non-destructive testing (NDT) inspection technique to determine the integrity of the wrap, depending on the type and severity of defects. ISO 24817 has stated the general techniques that can be used to inspect the composites overwrap repairs including Ultrasound Technique, Radiography and Acoustic Emission. However, Petroliam Nasional Berhad (PETRONAS) has performed a series of assessments on various inspection techniques to seek suitable inspection methods for the composite wrap system, composites/substrate interface and/or substrate. A total of 10 NDT techniques had been evaluated thus far including Laser

ARTICLE INFO

Article history:
Received: 26 February 2020
Accepted: 18 May 2020
Published: 16 September 2020

E-mail addresses:
sitihaslina@petronas.com (Siti Haslina Mohd Ramli)
rosmaar@petronas.com.my (Rosman Arifin)
hambali_chik@petronas.com (Hambali Chik)
* Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

Shearography, X-Ray, Microwave technique, Dynamic Response Spectroscopy (DRS), Acoustic Emission (AE), Computed Radiography (CRT), Pulse Eddy Current, Metal Magnetic Memory (MMM). This research summarises an overview of the effectiveness of the evaluated techniques and findings of the evaluation.

Keywords: Composite repairs, in-service integrity, NDT techniques

INTRODUCTION

PETRONAS has utilized composite repairs on piping, pipeline and equipment for the past 20 years. These composite repairs provide an effective and economical solution for extension of operational life, prevention of loss of containment and sustain the integrity of the assets. Composite repairs have the ability to strengthen as well as providing corrosion protection to the assets without disrupting the operation. The composite repair involves the application of an overwrap to a damaged or defective area(s) in order to strengthen or reinforce the defect area to restore the integrity of assets. The general guidance and requirements for qualification, design and applications of composite repairs are provided in ISO 24817 (2006) and ASME (2018).

There are two common types of composite repairs, the overwrap and preformed sleeve type. Under this assessment, the NDT techniques are evaluated on samples applied using ProAssure® composite overwrap repair system. This composite overwrap repair consists of composite laminate fibres (e-glass fibre) and a thermosetting epoxy resin that is chemically cured. The composite is manufactured under controlled conditions with the ratio of glass to resin accurately controlled and monitored.

All repairs have to be designed and applied under a specified, controlled process so that under the design conditions, there is a high degree of confidence that the repair will maintain its integrity over the design lifetime. However, there is a growing need to monitor their in-service integrity for repair lifetime extension and to better manage any loss of containment of the product. Nevertheless, inspecting composite repairs have many challenges including accessibility, inhomogeneous and anisotropic structure of composites, probability of detection, lack of adequate standards and diversity of composite materials amongst others.

Composite repairs inspection is part of overall integrity management activities that are required to be performed to ensure repairs are fit for purpose throughout its designed repair lifetime. To supplement this composite repair system, there is an increasing need for assurance that these repairs remain in good condition throughout its repair lifetime, and in certain cases, remain fit for use beyond its original repair lifetime. This approach will provide an opportunity for cost-saving of avoiding shutting down the equipment to allow for removal and replacement of composite repair with another permanent installation. In order to achieve this, identifying suitable tools to inspect and determine the condition of the composite repairs, are pivotal. Currently, whilst there are many inspection methods claimed to be able to perform an inspection on composites/composite repairs, the truth of the matter is, only a small percentage of techniques are actually suitable, and able to perform the inspection. Inspection methods used on composite repairs in other industries such as aerospace, marine and wind energy, include shearography, ultrasonics, infrared, thermography, and these are amongst the techniques that can also be considered for use in the oil and gas industry.

In order to identify suitable inspection techniques, PETRONAS has evaluated various potential non-destructive technique (NDT) from various technology providers. The objectives of the evaluation are to:

- Evaluate various inspection techniques for composites overwrap repairs.
- Demonstrate the applicability of the NDT technique for on-site inspection.
- Develop the allowable defects and acceptance criteria for the composite repairs system.
- Summarise advantages/disadvantages and restrictions for each NDT technique that have been tested and assessed with recommendations and way forward.

Current Practice

The current practice for inspection and monitoring of composites repair on oil and gas piping, pipelines and vessels is usually conducted based on ISO 24817 standard (2006) whereby visual inspection is generally performed to observe any irregularities on the composite repair surface like discolouration, cracks, chalking and blistering. This will usually be followed through with a coin tap test to detect any possible delamination/voids in composite and Barcol hardness testing to verify the curing of composite repairs.

The methods mentioned above serve as initial inspection tools to provide an indication of the condition of the repair. Any findings observed during these inspections would render the application of other non-destructive testing techniques to determine the integrity of the wrap, depending on the type and severity of defects.

Advanced NDT inspection techniques may be applied immediately after the repair system application as a baseline measurement or during the repair design lifetime. The NDT techniques are aimed to inspect both the substrate and composites repair system, to demonstrate the overall integrity of the repair system. Ideally, the NDT techniques are aimed to perform the followings:

- inspection of the repair laminate;
- inspection of the bond between the repair laminate and the substrate; and
- inspection of the substrate underneath the repair laminate.

The basic structure of a repair system in this context is considered in Figure 1.

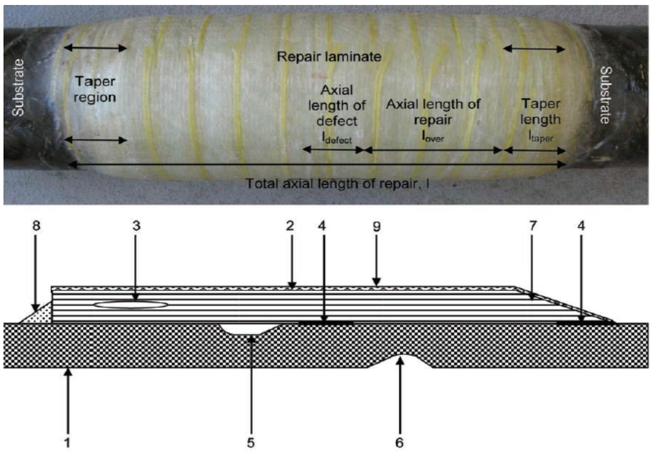

Figure 1. Schematic of the composite repair system and typical location of defects (ISO 24817 (2006))

INTEGRITY MONITORING OF COMPOSITE REPAIR SYSTEM

There is a growing need to monitor their in-service integrity of composite repair system to better manage and prevent any loss of product containment during the design lifetime of the repair system. However, inspecting composite repairs have many challenges such as accessibility, lack of adequate standards and availability of suitable tools for the industry. Current standards which are ISO 24817 & ASME PCC 2 provide general inspection requirements for overwrap i.e. frequency, size of defects & acceptance criteria. Thus, it needs further establishment to address the gaps and provide more details information on inspection requirements and integrity management of composite repair system. There are four critical elements to be established for the overall integrity of composite repair systems:

- Pre-application requirements (site survey, risk assessment and design)
- During application requirements (quality of material, surface preparation and qualified applicators)
- Post-application requirements (hardness test, visual inspection and baseline record)
- Operational integrity management (inspection and monitoring program)

Each element plays important roles in quality assurance of the repair system. The composite repairs inspection falls under operational integrity management throughout repair lifetime. For effective overall integrity management of composite repair system, each operator should establish clear roles and responsibility, and procedure in managing the integrity of composite. There should also be a nominated individual who will coordinate the repair application and in-service monitoring.

It should also be ensured that all required quality assurance (QA) documentation, test and inspection records are available and established including use of any NDT techniques for monitoring. The accuracy of inspection method and technology readiness for the NDT tools are significant to ensure integrity management of composite repair system is fully implemented.

With these challenges, the way forward is to assess which technologies are suitable, hence an in-house scheme of the experiment set up to achieve this objective, addressing the gaps in ensuring the suitable inspection tools are selected.

EVALUATION METHODS

ISO 24817 (2006) provides very general information on NDT techniques that can be used to inspect the composites overwrap repairs including Ultrasonic Test (UT), Radiographic Test (RT) and Acoustic Emission (AE). However, these techniques have not been validated for use in PETRONAS to inspect the integrity of the composite repairs. In view of this situation, PETRONAS has taken an initiative to perform a series of assessments on various NDT techniques that are available in the market which has potential to be endorsed as standard tools for inspection of composite repairs in PETRONAS.

Various technology providers were approached to seek for any suitable inspection methods for the composite repairs, composites/substrate interface and/or substrate. These technology providers would then propose a potential solution based on the technologies that they either own or operate under a license. Once the technology is deemed suitable or viable by PETRONAS, they are then requested to perform a live demonstration, witnessed by various representatives from PETRONAS.

Evaluation Process

For the evaluation process, the following steps were taken:

- Review of current practices and standards for inspection and monitoring of composite repair system
- Engagement with various parties of inspection companies'/service providers.
- Technology presentation
- Technology demonstration on test spool
- Evaluation of techniques

A total of 10 NDT techniques has been evaluated, and amongst the technologies that were assessed include:

- Laser Shearography
- X-Ray
- Microwave
- Dynamic Response Spectroscopy (DRS)
- Acoustic Emission (AE)
- Backscatter Computed Thermography (BCT)
- Electromagnetic Acoustic Transducer (EMAT)

- Computed Radiography (CRT)
- Pulsed Eddy Current
- Metal Magnetic Memory

However, three NDT technologies, Acoustic Emission Technology (AET), Backscatter Computed Thermography (BCT) and Electromagnetic Acoustic Transducer (EMAT) were not evaluated further during technology demonstration phase due to the unavailability of the equipment and /or principal for the demonstration purposes.

Technology Demonstrations

The demonstration was aimed to detect the embedded defects as well as to detect the interface and substrate. A test spool had been prepared and wrapped with few layers of composite overwrap repair system and embedded with simulated defects for blind detection by various NDT techniques. The test spool as shown in Figure 2, is constructed using a 10” API X65 pipe, with a few layers of composite overwrap repair. The simulated defects include disbandment, delamination, and void.

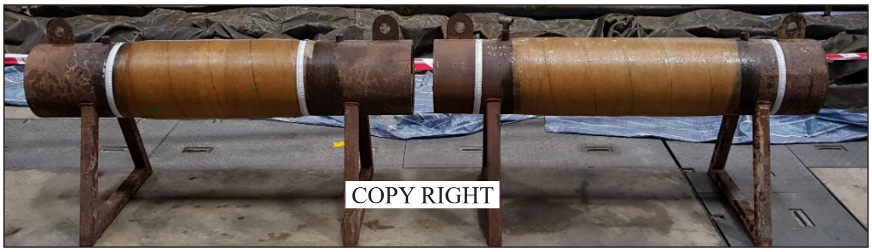

Figure 2. Test spool (Courtesy of PETRONAS Research Sdn Bhd)

A total of seven inspection techniques were demonstrated including the followings:

- Laser Shearography
- X-Ray
- Microwave
- Dynamic Response Spectroscopy
- Computed Radiography (CRT)
- Pulsed Eddy Current
- Magnetic Metal Memory

Separate sessions were arranged for each technology providers to perform their live demonstration, and evaluation was based on several criteria including time taken to perform, weight, ease of set-up, as well as other key criteria described in Table 1.

RESULTS AND DISCUSSION

The evaluation summary findings revealed mixed results.

Table 1
Evaluation summary and results

NDT Methods	On-line Inspection	Easy set-up	Portable	Detect defect	Measure defect	Classify defect	Repeatable
Laser Shearography	√	√	√	√	X	√	√
X-Ray	√	√	√	X	X	X	√
DRS	√	√	√	√	X	X	√
Microwave	√	√	√	√	X	√	√
CRT	√	√	√	√	√	X	√
MMM	√	√	√	X	X	X	√
Pulsed Eddy Current	√	√	√	√	X	X	√

The criteria in Table 1 were selected to ensure that the tools would be suitable for application in the oil and gas environment, and these would include on-line inspection during operation thus avoiding shutdown, easy to set up and portable, functions to detect/measure/classify the defects and can be repeatable for inspection at various locations. The ability of a tool to classify the defects is the probability that a feature is correctly identified by the tool, this includes the type of anomalies that are to be detected, identified, and sized by the tools shall be clearly indicated.

The evaluation showed that some techniques such as Laser Shearography, DRS, CRT, Eddy Current and Microwave techniques are able to detect the presence of a defect in the composite wrap, but the only shearography is able to classify the types of defects present in the overwrap. Whilst CRT is demonstrated to able to detect both the presence of defects in composite wrapping and substrate interface and measure the thickness of the substrate, it is not able to classify the types of defects present. Eddy Current technique, on the other hand, is only able to measure the thickness of the substrate. X-Tray technique is the only

Table 2
Summary of observations

Category	Criteria	Method
Category I	Able to detect the presence of defect in the composite repairs	i. Laser Shearography ii. Computed Radiography Testing (CRT) iii. Dynamic Respond Spectroscopy (DRS) iv. Microwave
Category 2	Able to detect the presence of defects in both composite repairs and substrate interface	i. CRT[1] ii. DRS
Category 3	Able to inspect the condition of the substrate	i. CRT ii. DRS
Category 4	Able to measure substrate thickness	i. Eddy current ii. CRT
Category 5	Unable to detect the presence of the defect	X-Ray

Note: 1. Limited to 10-inch pipe diameter technique which was unable to detect any defects in composites overwrap and substrate due to the low resolution.

Based on the evaluation and demonstration of various NDT technique conducted for composite repairs, the observations are summarized in Table 2.

CONCLUSION

Some technologies have shown the ability to inspect the composites repairs while some are observed to have additional advantages and are readily deployable. The way forward will include future technology refinement of the potential techniques to achieve technology readiness level (TRL) to meet PETRONAS requirements. As part of monitoring the performance and effectiveness of selected inspection tools, it is important that the NDT company provides information on the performance of anomaly detection, sizing and other measurement capabilities of their tool based on their in-house testing and collective of on-site verification. In conclusion, it is shown that each NDT technique evaluated has its own advantages and disadvantages, and the selection of which technique to use will be based on the repair condition, criticality, component to be assessed and accessibility.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the contribution and support from engineers and colleagues from PETRONAS Project Delivery & Technology Division (PD&T) including PETRONAS Group Technical Solutions (GTS), PETRONAS Research and Scientific Services Sdn Bhd (PRSB), PETRONAS Technology Management & Commercialization (TMC) and Center of Excellence (COE) PETRONAS Carigali Sdn Bhd (PCSB).

REFERENCES

ASME. (2018). *ASME PCC 2 repair of pressure equipment and piping*. American Society of Mechanical Engineers. Retrieved September 1, 2018, from https://myprecise.petronas.com/Pages/Home.aspx

ISO 24817. (2006). *Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection*. International Standards Organisation. Retrieved August 1, 2017, from https://myprecise.petronas.com/Pages/Home.aspx