Integrity Management of CRA Pipelines

Operator Experiences and Integrity Challenges

2015

PIPELINE
OPERATORS FORUM

Foreword

Although CRA materials are selected for their increased resistance to degradation in certain operating environments, Operators have suffered compromised integrity, and in some cases failures, of CRA pipelines. This has been verified through discussions within the Pipeline Operators Forum (POF) and wider subsea, pipelines and corrosion communities.

CRA materials have the potential for great engineering value as a barrier to corrosion threats which can otherwise dominate the risk profile of a pipeline; however, the current state remains that for all existing and proposed CRA pipelines, there is a need for greater understanding of the whole life-cycle requirements with regards to Integrity Management to ensure that these pipelines remain fit-for-purpose.

POF with this document aims to share experiences from member Operators and other contributing Companies (e.g. inspection service providers) in order to assist colleagues within the pipeline community by highlighting some of the key issues that need to be considered whilst developing Integrity Management Plans for CRA pipelines.

This document has been reviewed and approved by the Pipeline Operator Forum (POF). It is stated however, that neither the members of the POF nor the Companies they represent can be held responsible for the fitness for purpose, completeness, accuracy and/or application of the contents of this document.

Acknowledgement

The Pipeline Operators Forum (POF) would like to thank BP Exploration, Shell, Petrobras, ExxonMobil, Statoil, Total and ConocoPhillips for their cooperation in sharing best practices, lessons learned and for providing the draft version of these Guidance Notes to the POF for further development and circulation. POF would also like to thank GE, NDT, Quest Integrity and Halfwave for their review and technical input to section 9.

Photographs used in this Guidance Note have been provided by and are used with permission from a number of sources.

Table of Contents

1 Scope

This document captures challenges that operating companies have experienced whilst managing the integrity of CRA pipelines within the oil and gas industry. The main input has been from subsea (flowlines and risers) and onshore pipelines but, where appropriate, information relating to process piping in topside or production units has also been included.

Each pipeline operating company will have practices and procedures for developing pipeline integrity management plans. The document is provided to assist in the development of these plans for CRA pipelines by raising awareness of issues that can impact the integrity of the pipeline and the ability to manage the integrity throughout the life of the pipeline.

This document is based on CRA materials for which experience has been gained in operating environments. Typical examples are 13Cr, 316 SS, Alloy 625, Alloy 825, Duplex and Superduplex stainless steel, but the lessons learnt can be applied to other CRA materials. The pipeline may be of solid CRA or a carbon steel carrier pipe with CRA cladding or liner.

2 Introduction

Pipelines using Corrosion Resistant Alloy (CRA) materials are not common, due largely to the cost, but they are increasing in number and length throughout the world and, although this is a maturing technology, there are still some issues and concerns that Operators face during the operational life of these pipelines. The advantage they offer with regard to corrosion resistance means they are now becoming more popular. Production fluids often contain a high sulphur or CO2 content that requires the use of materials suitable for corrosive environments. When the H2S and CO2 contents are too high for the corrosion resistance properties of carbon steel, a CRA is often employed.

Pipelines may be of solid CRA material like e.g. 13 Chrome, Duplex Stainless Steel or Super Duplex Stainless Steel. For onshore and offshore pipelines however, that need to achieve a balance between cost, the mechanical properties of a CMn tube steel and the corrosion resistance properties of a CRA, clad or lined pipes can be used. Both clad and lined pipes consist of a carbon steel pipe which has a layer of CRA in contact with the production fluid and hence, its corrosive environment. In the case of clad pipes, the layer of CRA is applied using different procedures that create a metallurgical bond, while in the case of lined pipe an internal CRA pipe is connected to the external carbon steel pipe through mechanical bond.

During recent years intensive research effort has been carried out by companies and research institutions worldwide and more information is now available regarding some stages of a CRA pipeline life, mainly design and installation. However, limited information is available about the integrity management challenges that Operators have faced throughout the life of a CRA pipeline. In order to contribute to fill in these gaps, POF has conducted a survey among its members trying to identify the main issues Operators face and how they deal with them during the full life cycle of the CRA pipelines, i.e. from design, fabrication, installation and commissioning A questionnaire survey was conducted so that all information presented here is based mainly in actual field experience (field proven solutions).

This document consolidates good practices and experiences from contributing Operators in order that these may be considered by others whilst establishing Integrity Management Strategies for their CRA risers and pipelines. The document considers the full life cycle i.e. from design, pipe fabrication, construction, installation, commissioning, operation and decommissioning, in order to highlight potential threats and, where appropriate, indicate possible mitigation measures to prevent impacts on the integrity of the pipeline system.

Material selection and fabrication procedures are important aspects of oil and gas production system design. If non-suitable materials and/or fabrication procedures are selected, then premature failure may result with potential safety and environmental damage implications , lost production and considerable costs of line repair and/or replacement. This guidance does not cover the selection of materials or the preparation of fabrication procedures other than to highlight the potential failure mechanisms that can have impact on the integrity of the pipeline during operations. The selection of the CRA material appropriate for the process conditions and the preparation of the fabrication and installation procedures require specialist knowledge and expertise.

The use of CRA materials introduces specific challenges during all stages of the pipeline life cycle from design to operational aspects like integrity monitoring and inspection during operation. These are highlighted within this document.

This document does not replace the need for SMEs from the pipeline Operator, or on behalf of them, to be involved throughout all stages of the pipeline life cycle to gain assurance that the appropriate Integrity Management Strategy is implemented and that the required levels of inspection, testing and certification are completed.

3 List of Acronyms

For the purpose of this document report, the following acronyms apply:

ART	Acoustic Resonance Technology
CMn	Carbon Manganese
CRA	Corrosion Resistant Alloy
CS	Carbon Steel
EC	Eddy Current
EMAT	Electro Magnetic Acoustic Technology
GW	Guided Waves
HISC	Hydrogen Induced Stress Cracking
ID	Inside Diameter
ILI	In-Line Inspection
IM	Integrity Management
MEC	Magnetic Eddy Current
MFL	Magnetic Flux Leakage
MIC	Microbiologically Influenced Corrosion
NDT	Non-Destructive Testing
OD	Outside Diameter
PA	Phased Array
PDAM	Pipeline Defect Assessment Manual
QA	Quality Assurance
QC	Quality Control
RT	Radiographic Technology
UT	Ultrasonic Testing
SCC	Stress Corrosion Cracking
SCR	Steel Catenary Riser
SLOFEC	Saturated LOw Frequency Eddy Current
SME	Subject Matter Expert
SSC	Sulfide Stress Cracking
TOFD	Time Of Flight Diffraction

4 Integrity Management

4.1 CRA Threats

The first step in the integrity management of any asset is to understand and identify all potential threats to the asset at all stages of life. A credible threat is one that is expected to result in corrosion, erosion or environmental cracking in the pipeline or associated components, based upon a combination of the material, loading conditions and the environment under consideration. The deterioration of a CRA pipeline is often seen as an unlikely event since designers, installation companies and Operators tend to consider that these materials have superior metallurgical properties and are able to withstand any eventual threat. This is obviously not the case, since Operators have experienced issues with CRA pipelines. Whilst the use of CRA provides increased resistance to corrosion over carbon steel, CRA pipelines can be susceptible to degradation and therefore a detailed pipeline integrity management plan is still required. Potential threats to CRA include but may not be limited to:

- Chloride Pitting Corrosion
- Hydrogen Induced Stress Cracking (HISC)
- Sulphide Stress Cracking (SSC)
- Stress Corrosion Cracking (SCC)
- Pitting Corrosion
- Crevice Corrosion
- Galvanic Corrosion
- Chloride Stress Corrosion Cracking
- Microbiologically Influenced Corrosion (MIC)
- Erosion
- Abrasion
- Fatigue

Both erosion and corrosion (mainly pitting) and fatigue cracking, more specifically in SCR and in flowline free spans, are possible threats to CRA lines. Additional threats to CRA lines include sea water corrosion (as part of construction or pre-commissioning processes) and pipe wall erosion as a result of changes in the operating conditions (temperature, chloride, reservoir performance and sand) and/or incorrect use of the material. CRA's may have an increased resistance to MIC's, however, MIC is still a threat to a CRA pipeline. CRA clad or lined pipelines continue to be subject to the same external corrosion threat as for any other carbon-steel pipeline.
It is anticipated that the external corrosion mechanisms are controlled by coatings and cathodic protection. However, the application of cathodic protection to a CRA pipeline may introduce the threat of HISC (see example in figure 1). Criterion for protection to avoid HISC should be defined and implemented, usually achieved by management of CP potentials. A recommended practice for duplex stainless steels is document DNV-RP-F112: Design of duplex stainless steel subsea equipment exposed to cathodic protection.

Figure 1. – HISC of Super 13Cr due to exposure to seawater with cathodic protection applied

4.2 Integrity Management Plan

The integrity management plan (IMP) should be defined for all stages of the CRA pipeline life cycle. Each stage of the life cycle will contain specific risks to the integrity of the CRA pipeline and therefore needs to be considered individually. For example, contamination of the CRA with ferrous debris may be a risk during pipe fabrication and construction whilst the exposure of the CRA to sea-water may be a risk during installation and pre-commissioning.

The IM Plan for each stage of the CRA pipeline life cycle should identify any potential for a defect to be undetected. This will then feed into the IM Plan for the subsequent stage and will finally determine the extent of inspection required to provide the assurance that the pipeline is fit for operation as well as the proper adjustment to IM Strategy. Therefore IMP for CRA pipeline operation should consider all defects that have been identified during the previous stages, the remedial actions that have been performed, the potential defects that may have been undetected together, and any defects that may be introduced during operation.

It is important that the QA/QC activities performed at each stage is appropriate for the potential defect morphology or threat associated with the particular risk. High levels of QA/QC during pipe fabrication, pipeline construction, installation and commissioning are required to ensure that defects are not introduced in to the pipeline that is to be put in to operation. The significance on monitoring the integrity of the CRA throughout all project stages is not always well defined in project procedures or standards and the implications to the future integrity of the pipeline is not always well understood.

If a CRA pipeline is outside the fluid service limits set for that particular material, then the pipeline may be subject to corrosion and/or cracking. If these should occur, the failure mechanism may progress very rapidly although this is not always the case. The significance of monitoring the critical process conditions is not always well defined in operations procedures or IM strategies. This should be reviewed as part of the wider pipeline revalidation program.

As any other equipment, CRA pipelines are susceptible to mechanical damage. Dents may prove difficult to assess and fix compared to carbon steel pipelines. The Pipeline Defect Assessment Manual (PDAM) does not currently address CRA pipelines and therefore the assessment of any defects requires specialist advice.

A CRA pipeline may consist of a number of sections which may have differing design criteria (e.g. pipeline and riser), different installation techniques (e.g. off-shore and on-shore sections), different intervention means (e.g. diver accessible depths or not) or differing operating conditions (e.g. large temperature differential). These differences should be considered when developing the IM Plan and, where appropriate, different plans for different sections should be developed.

5 Design

During the design phase of a project the appropriate CRA will be selected to resist chemical processes and other degradation mechanisms that may be present during the whole life of the pipeline. The chosen CRA will have performance limits. The key barrier to prevent deterioration of the CRA during pipeline operation is in selecting the appropriate material for the service conditions. Established Domain Diagrams, setting out the critical process conditions, have been validated for the intended service conditions. Where these have not been defined and validated, requalification during the design phase of a project may be required. The material selection should always consider the latest published data and the results of any recent industry testing that has been carried out. Consideration should include that CRA liners and cladding can reduce the effectiveness of internal inspection techniques, such as UT and MFL, to inspect the carbon-steel substrate.

Ensuring that the pipeline conditions remain within the performance limits of the CRA is important. The design of the process controls and monitoring systems is critical to ensuring the integrity of the CRA pipeline. Process conditions that may require control and monitoring include but are not limited to:

- Temperature
- Pressure
- Strain
- Cl content
- H2S content
- CO2 content
- pH level
- 02 content
- Particulates/ Flow Rate
- Biocide/Inhibitor
- Produced water content

The selection of the CRA should make due consideration of the potential for the process conditions to change during the life of the pipeline. This could be due to the change in fluids from a particular source or could be due to potential development of a pipeline network which introduces fluids from other sources.

The design will determine whether the pipeline will be solid CRA or a carbon steel pipeline either lined or clad with CRA. Each of these options provides differing challenges to the ability to monitor the pipeline integrity. Manufacturing and installation factors should also be considered when determining whether a lining, cladding or weld overlay should be used. Lined pipe is not recommended for manufacturing bends, CRA may be applied to seamless pipe as a lining or weld overlay, however, solid alloy may need to be used for components that cannot be easily clad or applied with weld overlay. Cladding or weld overlay with a CRA, can offer the same corrosion resistance as a solid equivalent of the same material. However, as a cladding, or weld overlay is typically only a few millimeters thick, it can be subject to mechanical damage through manufacture, installation, commissioning or inspection, as well as corrosion damage during commissioning or in-service. Unlike a solid CRA component, damage to a thin CRA cladding or a CRA weld overlay, will result in the exposure of a carbon steel substrate, which will suffer from higher rates of corrosion than the cladding.

In the design phase the requirement for pigging needs to be assessed for both operational efficiency and Integrity Management. It is recommended, as a base case, that CRA pipelines should be designed with pigging capabilities. There have been instances where CRA pipelines have been designed and installed without the facilities required to pig the pipeline but where the requirement for pigging has been identified during operations and therefore the facilities have had to be subsequently installed. Additionally, pigging may be of benefit for under-deposit corrosion, MIC and flow assurance.

Once the design options have been selected a key part of the design process should be to prepare the initial pipeline IMP, to ensure that the necessary controls can be put in place to maintain the integrity of the pipeline. This should consider the ability to monitor and inspect the pipeline, the required analyses and tests and procedures to be utilized to assure and demonstrate the integrity of the pipeline at all stages.

6 Pipe manufacture

6.1 Manufacturing Processes

In the table below an overview of CRA pipe manufacturing processes, their abbreviation and applicable codes/standards is given.

Type of CRA pipeline material		Codes/Standards
CRA-S	CRA-Solid: Solid CRA pipe material. Fabrication process: seamless (hot rolled or centrifugally cast) or longitudinally seam welded.	API-5LC DNV-OS-F101
CRA-C	CRA-Clad: Layer of CRA material is metallurgically bonded to a carbon steel substrate. Fabrication process: longitudinally seam welded pipe made from hot rolled or explosion bonded CRA layer onto a carbon steel plate	API-5LD DNV-OS-F101
CRA-L	CRA-lined: A thin liner pipe of CRA material is placed within a carbon steel substrate pipe but not metallurgically bonded to it. Depending on the process of fabrication however, it might be a very tight shrink-fit. Fabrication process: longitudinally welded or seamless liner which is expanded in a carbon steel pipe.	API-5LD DNV-OS-F101
CRA-O	CRA-Overlay: CRA material is applied by fusion welding and metallurgically bonded to the carbon steel substrate pipe. Fabrication process: Welding with an as welded or machined surface finish. *Note: typically used at the inside of pipe ends of CRA-L pipes and cladding of fittings.*	API-5LD DNV-OS-F101
CRA-H	CRA-HIP: CRA powder is applied by Hot Isostatic Pressing (HIP). *Note: as far as known, this process is not in use to produce CRA pipes although has been used for subsea manifolds.*	
CRA-T	CRA-Thermally Sprayed: a thin layer of CRA is applied by thermal spraying to a carbon steel substrate. The layer may or may not be metallurgically bonded. *Note: as far as known, this process is not in use to produce CRA pipes and therefore not discussed further.*	
CRA-E	CRA-Centricast: a layer of CRA material is applied by centrifugal casting to a carbon steel substrate. The layer is metallurgically bonded. *Note: as far as known, this process is currently not in use to produce CRA pipes and therefore not discussed further.*	

Table 1. – CRA type of pipeline materials and respective standards

6.2 QC/QA applied during pipe fabrication

Pre-qualification of the materials and supplier(s) based on the pipeline media in combination with the operating conditions is advised as one of the first steps during material purchase.

General inspection and testing requirements are described in the codes and standards as listed in Table 1. In addition to the requirements in these documents, Operators quite often specify extra inspection activities, specific inspection / NDT techniques or tighten acceptance criteria.

Some of the advised additional and specific inspection techniques / criteria are:

- Inspection of the (accessible) clad surface for defects or surface iron contamination with the Ferroxyl test, as per ASTM A380 (e.g. for welded overlay surfaces). It is recommended to be applied by experienced personnel who are familiar with the limitations of this method of testing.
- Inspection of coarse grained austenitic steel (girth) welds with compression wave UT probes due to

the coarse grain micro-structure. Compression waves are more suitable to penetrate such welds, but applying this technology requires additional training.

- For automatic UT inspection it is advised to require a signal to noise ratio of the reference signals of at least 12 dB (signal height from reference defect > 4 x noise level height).
- PMI (Positive Material Identification) of the internal CRA weld overlay material of CRA-C pipes if possible (e.g. for 1 out of 10 pipes).

6.3 Cleanliness Requirements

Segregation and preventing cross contamination during the manufacturing process is important to ensure the long term integrity of the CRA.

Example shown in Figure 2 is scale on the inner surface of a CRA lined section of pipe which has been produced due to ferrous contamination during the pipe manufacturing process. Whilst this may be superficial and the immediate impact on the integrity of the CRA minimal, the impact during operations if left untreated could be more significant (e.g. crevice corrosion may develop) and in particular the potential for future internal inspection of the pipeline would be compromised.

Figure 2. – Example of contamination of CRA surface of lined pipe section

7 Pipeline Construction & Commissioning

Operators' experiences with CRA pipelines have highlighted the importance of QC/QA during the various project stages. A significant proportion of the reported defects identified in CRA pipelines result from practices employed or incidents that occurred during installation and commissioning of the pipeline. The management of the integrity of the CRA during these project stages is imperative to ensure that latent defects are not transferred to the operating phase.

7.1 Welding

Welding of CRA is a key issue as it can have a serious detrimental impact on the overall performance of the CRA and therefore the pipeline integrity. Whilst weld procedures will be prepared, and tests carried out to qualify the procedure, there also needs to be stringent quality control during the welding processes to ensure that the welding is completed as intended.

Quality assurance of the weld preparation is particularly critical for CRA pipelines and components. Figure 3 shows an example of the resultant corrosion following incorrect weld preparation. The preparation for the weld had completely removed the CRA cladding adjacent to the weld area to such an extent that, following completion of the weld, an area of exposed carbon steel remained resulting in loss of the carbon steel and a subsequent leak.

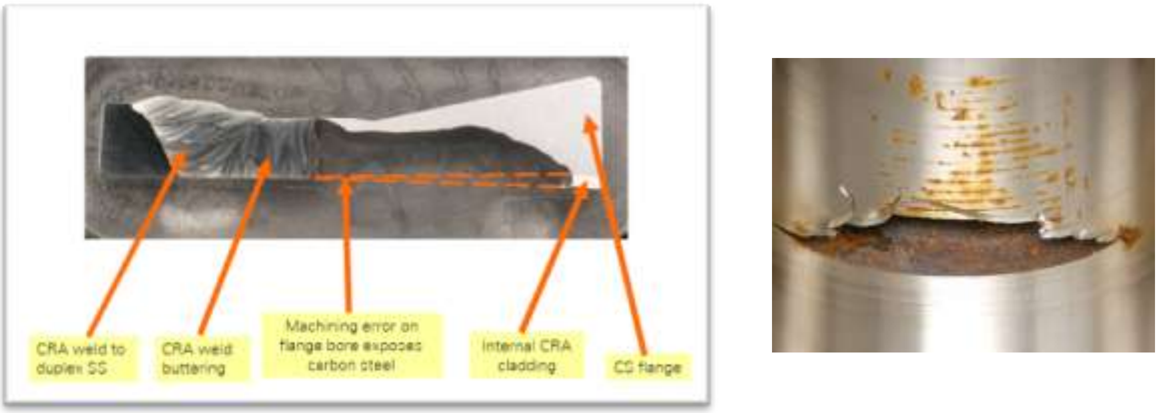

Figure 3. – Corrosion of a weld overlay clad flange resulting from poor weld preparation

Quality control during the welding process is also critical. Figure 4 shows an example of corrosion in a CRA clad pipeline which was caused due to the use of carbon steel for the weld root rather than a CRA consumable. This was not identified during the execution of the weld and could not be determined by the weld inspection. The subsequent corrosion of the weld root eventually exposed the carbon steel section of the pipe behind the cladding. Due to a fabrication mistake all superior performance of roll bonded clad pipe was jeopardized.

Figure 4. – Corrosion of clad pipeline due to incorrect material used for weld root

7.2 Installation

The way in which the pipeline is installed has the potential to impact the integrity of the CRA pipeline. For example the design of an off-shore pipeline called for snake lay (i.e. the pipeline to be installed with a zig-zag route) to manage excessive buckling/local bending during operations. However, the post installation in line inspection identified that the selected pipeline profile had introduced numerous minor geometrical deformations in the CRA liner caused through localized variations in the longitudinal stress and strain. The deformations were either wrinkles (as shown in Figure 5), circumferential deformations close to the girth welds or individual dent-like deformations. Whilst these do not pose an immediate threat to the integrity of the pipeline as, in this case, the liner has remained intact further assessment was required to confirm the ability of the liner to meet the long term requirements. The deformations also impact the ability to internally inspect the pipeline.

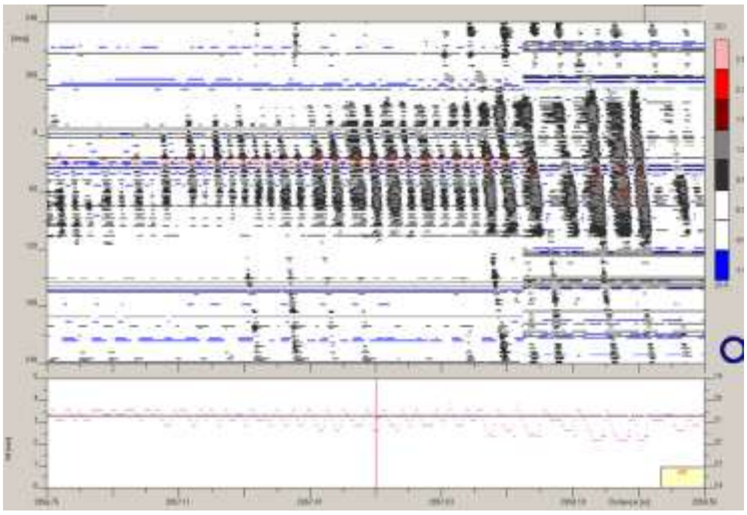

Figure 5. – Inspection results showing wrinkles in CRA liner

7.3 Seawater Ingress

During installation, testing and commissioning of offshore pipelines there may be times during which the CRA could be exposed to seawater. This could have significant impact on the CRA depending on the CRA alloy used, chloride concentration, dissolved oxygen content and the temperature. Figure 6 below shows a reported feature within a CRA clad pipeline that had been exposed to seawater during installation. Pitting of the CRA had occurred and at certain locations the CRA layer had been breached exposing the carbon steel.

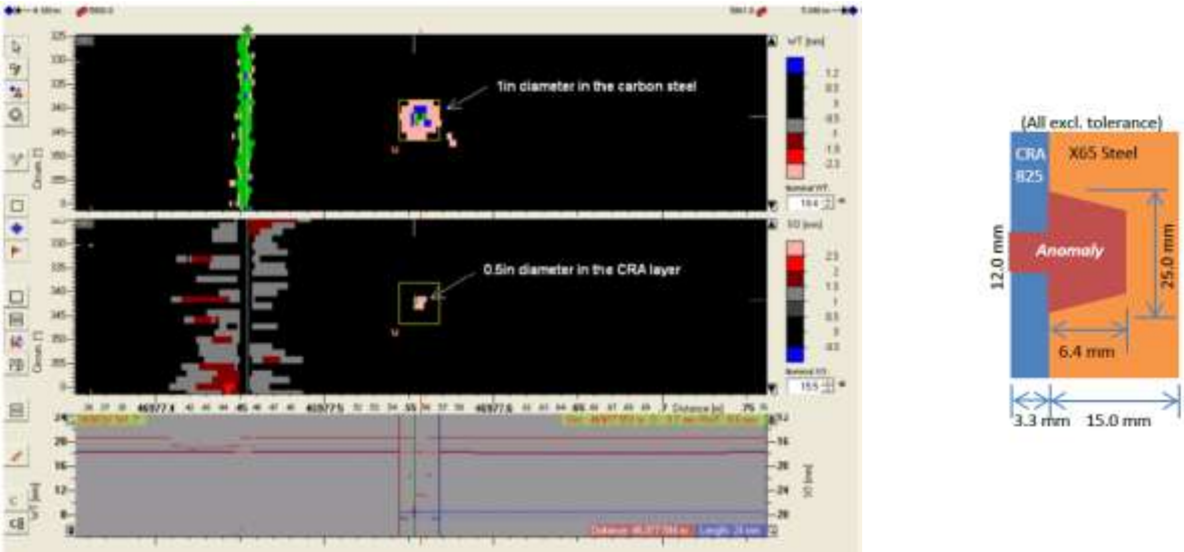

Figure 6. – Perforation of CRA layer due to exposure to seawater

Figure 7 provides a further example of the damage caused to a 13Cr pipeline exposed to seawater during commissioning.

Figure 7. – Pitting of Super 13Cr due to exposure to seawater

8 Operations & Inspection Planning

The Operator should be able to demonstrate, at any time, that a pipeline system is and remains fit for purpose. Potential threats can be identified by risk assessment and to some extent may be mitigated by implementing a variety of monitoring and/or inspection activities, usually captured in an IM plan. Applicable (national) legislation may also oblige certain prescriptive requirements.

8.1 Integrity Monitoring & Control

As part of the integrity management of the CRA pipeline, it is critical to monitor and manage the pipeline environment and conditions:

- Relevant process conditions, listed in Section 5, should be monitored to provide confirmation that the operations have remained within the set limits.
- Monitoring and assessment of strain associated with buckling and spanning may also be required.
- The frequency of sampling needs to be sufficient to identify any excursions, the extent of the excursion and the duration.
- The pipeline operating procedures should identify the actions to be taken should excursions occur which could include the pipeline continued operation, inspection or immediate shut-down.
- For subsea CRA pipelines prevention of sea water ingress may need to be considered. For example, the risk associated with sea water ingress during pipeline depressurizations, interventions, etc. should be considered.

8.2 Baseline Condition

An early assessment of the pipeline will set the “baseline” against which future integrity management plans can be developed and inspection results can be compared. The benefits of the baseline assessment also include verification of the manufactured/installed state together with early identification of any potential integrity threats, as previously identified in this document.

The Operator should determine how the baseline assessment is to be achieved. For positive validation (i.e. based on actual inspection results) that the CRA barrier is intact throughout the pipeline, then ILI is the most appropriate technology if the tools are correctly selected and deployed under the right conditions. However the success and outcome will be dependent on the nature of the CRA pipeline (solid, mechanically bonded or metallurgical clad). Alternative means of assessment, such as detailed review of project QA/QC records, may carry more uncertainty than ILI, but may be acceptable based on review and risk assessment of the integrity management activities that have previously been completed. The nature of the baseline assessment varies amongst companies and applications.

The timing of any baseline survey needs to be considered. Baseline surveys could be conducted prior to operations in order to establish the condition of the pipeline prior to the introduction of hydrocarbons. Alternatively a baseline could be conducted following a pre-determined period of operation. Some Operators recommend baseline surveys be conducted during both periods.

CRA materials are known to be effective for well-defined operating regimes. Therefore, if the baseline condition is known, evidence to demonstrate that operating conditions have remained within defined limits may possibly be considered sufficient to revalidate the pipeline against internal corrosion threats.

8.3 CRA management during operational life

Baseline inspection may detect and permit remediation of some potential defects introduced in to the pipeline prior to its operation. The pipeline design will have selected a CRA material that is suitable for the predicted operating envelope and the potentially highly corrosive environments in the pipe. However the CRA may still be susceptible to corrosion or cracking under conditions which may result from long term operations outside of defined operating limits or short term upset conditions. It is important that process monitoring is in place to identify any loss of control or change in operational conditions.

When excursions outside of defined operating limits occur an assessment will be required to determine the potential damage that could have occurred. In such instances, it may be necessary to inspect the pipeline and therefore the Operator needs access to the appropriate inspection technology.

The IM plan set out for the pipeline may require periodic inspection of the pipeline. The inspection may be targeted at defects in the CRA or, for lined or clad pipelines, the carbon steel or both. Inspection of the carbon steel may highlight instances of external defects but may also highlight areas where there are breaches in the CRA.

There is potential to damage CRA pipelines during either routine or inspection pigging operations. Consideration should be given to both mechanical damage and metallurgical contamination. Pig discs have been known to fail and could lead to the pig body scoring the relatively soft CRA material. This is even more detrimental if it occurs in clad or lined pipes and exposes the carbon steel backing material. Further, care must be taken to avoid metallurgical contamination of CRAs, such as by designing pigs with non-carbon-steel brushes. The risk of other metallic contaminants within the flow, such as failed chokes, valve internals etc. should also be considered.

9 Operational Inspection Technology

9.1 In Line Inspection

The only technology with the capability to inspect the whole pipeline 'end to end' is In-Line Inspection (ILI) pigging. Current ILI technology was however generally developed for the inspection of carbon steel pipelines and so there are limitations when used to inspect pipelines which are CRA or contain CRA sections.

CRA pipelines can be pigged, without damage. Pigs, also referred to as tools, can be designed to inspect CRA lines without damaging liners / cladding, avoiding metal to metal contact between pig and pipeline. Risk of pigging should be considered prior to any ILI run. Risks include damage to the CRA, potentially sticking the tool in the line, data reliability, and other operational risks. These risks should be considered in a risk assessment prior to any inspection campaign.

Different types of tools are available and these can be equipped with various inspection equipment:
- Free swimming tools that can cover large distances
- Tethered (cable operated) tools for shorter distances also allowing additional features
- Crawler tools

9.1.1 UT Tools

An ultrasonic pulse generated by a transmitting/receiving transducer will travel at constant speed through a liquid and at constant, but different, speed through steel. When passing from a liquid to steel, part of the energy in a pulse will reflect from a solid steel surface, generating a return pulse, and part will be transmitted into the steel, resulting in an ultrasonic pulse which propagates through the steel. When passing through steel, most of the energy in a pulse will reflect from the outer steel surface and return to the transmitter/receiver. The time elapse between sending and receiving the ultrasonic pulses is representative for the pipe wall thickness and location of metal loss (internal/external if present). An example is depicted in Figure 8. The transmission of energy across a steel/gas interface or through gas to the steel surface is much less efficient than at a liquid/steel interface, making standard UT tools ineffective in a gas environment.

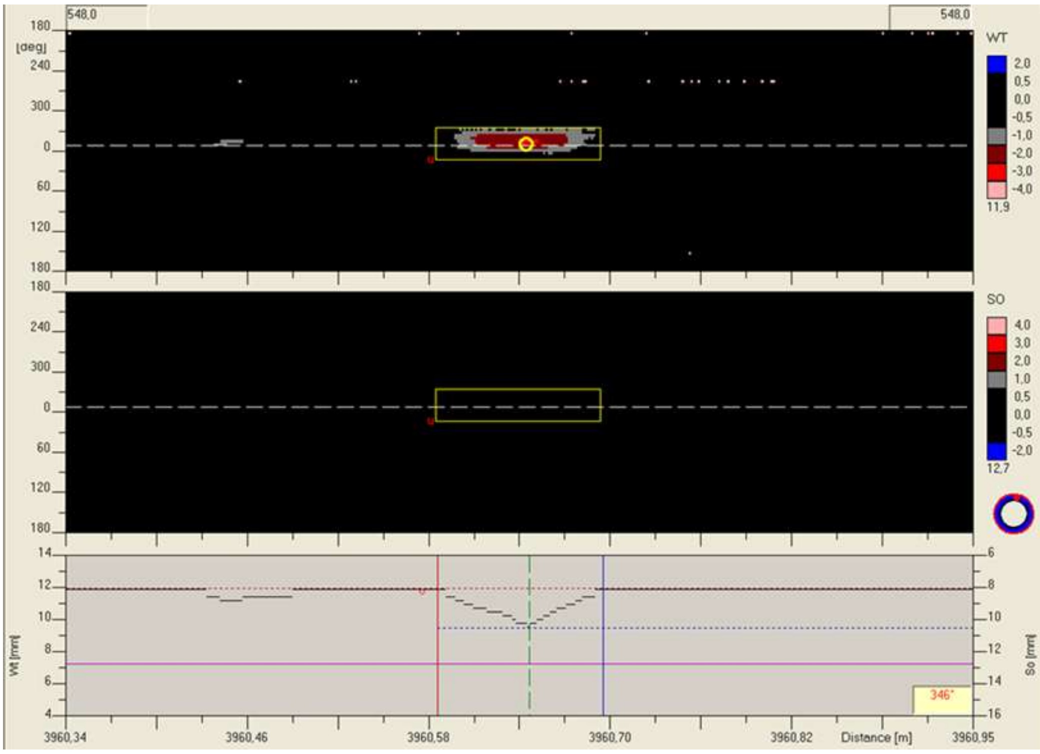

Figure 8. – UT ILI of external metal loss in Duplex pipe

On a flat surface, the pulses are easily identifiable as discrete entities, whereas, where they are reflected from an uneven surface, such as an un-machined inner surface of the pipe following weld-overlay cladding, the pulses spread out and can merge. Furthermore, there may be more than two pulses reflected by the steel wall, which has the potential to confuse the measurement of the timing device. Where there are concerns regarding the surface finish, the impact should, wherever possible, be confirmed by pull-through test using sample of the actual pipe (a pipe sample of 1m length would suffice). As a general rule, surface roughness of 0.1 to 0.2mm will not have an impact on signal quality. Figure 9 gives an example of the UT inspection result in carbon steel pipe with weld overlay.

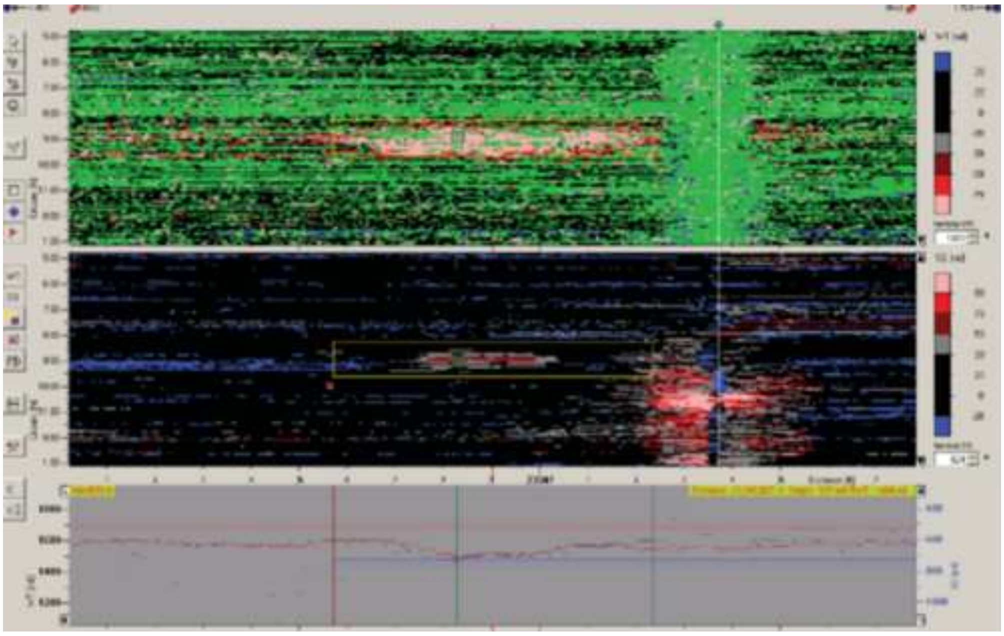

Figure 9. – UT ILI of internal metal loss in carbon steel pipe clad with Alloy 625 weld overlay

The speed of sound within a CRA material is practically similar to carbon steel and therefore, if the CRA is metallurgically bonded to the carbon steel there will not be reflection of the UT pulse at the interface and hence the UT tool will record the combined material as one wall thickness. However if the materials are not metallurgically (fully) bonded as in the case of lined pipe, the energy of the UT pulse will be reflected at the interface generating an interface echo. For lined pipe therefore, the UT tool will record the thickness of the CRA layer only, there will be no results recorded for the carbon steel.

Free swimming and tethered tools can be equipped with UT technology for corrosion detection (wall thickness measurement) and crack detection.

Specially developed tethered tools are available with the Time Of Flight Diffraction (TOFD) technique. These tools can be accurately aligned to a girth weld and used to detect and size external fatigue cracks. Tools based on TOFD technique are better than traditional UT tools with respect to sizing of small cracks whilst traditional UT tools are better at detection of small cracks. Therefore a combination of traditional UT, for detection of small cracks, and TOFD for sizing of small cracks can be applied.

9.1.2 MFL Tools

Austenitic CRA (e.g. 316, 625, 825) is not magnetic and does not influence a magnetic field. Therefore an MFL tool cannot be used to inspect austenitic CRA.

Martensitic CRA (e.g. 13Cr) or Austenitic/Ferritic CRA (e.g. Duplex) does have some magnetic property and therefore it is possible to inspect these CRA using an MFL tool although the performance of the tool will be significantly different to that in carbon steel and therefore a revised performance specification will be required. The development of the performance specification will be required on a pipeline by pipeline basis, through testing on sample spools.

For pipelines clad or lined with austenitic CRA it is possible to inspect the carbon steel behind CRA using MFL. The thickness of the CRA layer causes an increased distance of the magnets and sensors from the carbon steel layer which influences the defect detection capability of the tool. The CRA causes a sensor lift-off influencing the magnetization and therefore any defect signals. Additionally, if the CRA layer is electrically conductive then the transient magnetic field produced by a passing MFL tool will generate eddy-currents in the CRA layer. In turn this will produce a magnetic field in opposition to that generated by the tool. This could potentially affect magnetic field levels in the pipe-wall as well as defect response. The thicker the CRA layer, the lower is the maximum allowable carbon steel thickness. Within limits, this effect may be compensated for by running the inspection tool at reduced velocity. Pull through tests will be required for each application to determine the actual impact of the CRA and to develop the appropriate performance specification for the inspection tool. It is important that these pull through tests are performed with pipe samples representing the full range of thickness for both the CRA and the carbon steel. Figure 10 gives a detailed example of the MFL inspection result in carbon steel pipe with 316L clad layer.

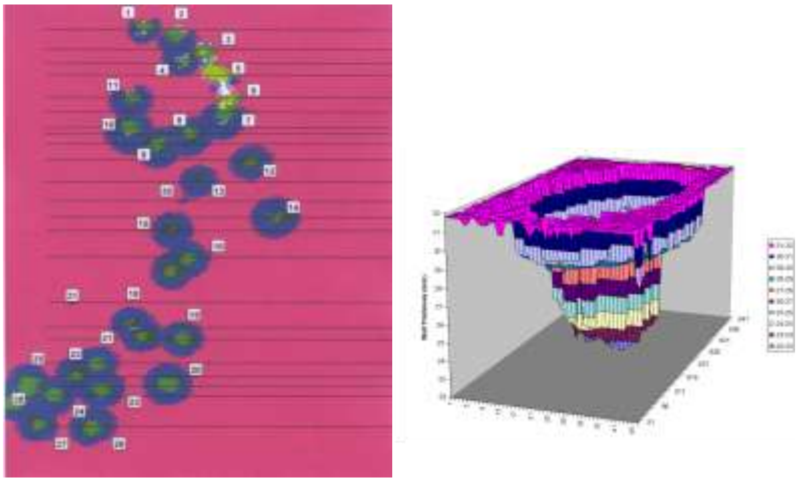

Figure 10. – Features identified during MFL inspection of carbon steel pipeline clad with 316L - Feature dimensions confirmed by external TOFD

In addition to the issues related to the inspection of pipelines clad or lined with austenitic steel, the MFL inspection of pipeline clad or lined with Martensitic CRA is more complicated as the CRA layer cannot be simply treated as increased stand-off.

9.1.3 EMAT Tools

EMAT tools need to magnetize the pipe wall in order to generate ultrasonic pulses inside the pipe wall. In case of non-magnetic CRA, the CRA layer itself cannot be inspected. Moreover, the non-magnetic CRA layer then causes an increased distance of the EMAT sensors from the carbon steel (lift-off); therefore, depending on the thickness of the non-magnetic CRA layer, also the carbon steel behind cannot be inspected.

The sensors on an EMAT tool can be of many different types and their performance in CRA pipe will vary. However all will have significantly reduced inspection performance due to poor electrical conductivity and low magnetostriction in austenitic CRA compared to regular pipeline steel. Note: magnetostriction is a property of ferromagnetic materials that causes them to change their shape or dimensions during the process of magnetization. This poor performance can be partially overcome by systems that move slowly compared to typical free-swimming tools and therefore allow for increased numbers of measurements using the sensors.

For magnetic stainless steels, such as Ferritic stainless, Duplex or Martensitic, the performance of the EMAT tool increases compared to operating in the austenitic CRA steels, potentially allowing inspection of these materials at velocities typical for free swimming tools. However, CRA alloys differ in magnetic properties so much that tests on sample spools of the specific pipeline alloy need to be performed to confirm the effectiveness of the sensors in advance of an inspection run.

Another factor which will affect the EMAT tool is the physical nature of the CRA within the pipeline itself. An EMAT tool will not be able to inspect a CRA lined pipe where there is no metallurgic bond between the CRA and the other pipe material. For a pipe which is fully composed of CRA steel, inspection should be possible subject to the limits described above. For a pipe where carbon steel and CRA lining are metallurgically bonded, tests on sample spools must be performed to ensure that the performance of the EMAT meets the desired specification in these materials.

9.1.4 EC Tools

Eddy current tools measure metal loss features on the inner surface of the pipeline.

In principle, the eddy current inspection technology is applicable to CRA as the required material property is its electrical conductivity. However, the response of the inspection tool will differ from that in carbon steel. Therefore prior to any inspection of a pipeline containing CRA pull tests will be required to determine the actual performance of the tool.

9.1.5 Magnetic Field Strength Tools

A permanent magnet with a sensor is used to measure the magnetic field strength. The measured magnetic field strength will be affected by the presence of and distance to ferromagnetic material (such as carbon steel) near the magnet. In this way the distance between sensor and carbon steel surface can be measured. The trade name of a tool based on this technology is DMR™ (Direct Magnetic Response). As an austenitic CRA layer is not ferromagnetic, the tool can be calibrated to measure the distance between the inner surface of the internal CRA layer and the carbon steel substrate for both CRA-C and CRA-L pipe material. The technology can detect wrinkles in CRA-L pipes, corrosion defects under the CRA layer and measure the thickness of the CRA liner/layer.

9.1.6 ART Tools

A sending transducer transmits a broad-band acoustic signal towards the metal structure of interest. The signal spreads in the structure, exciting half-wave resonances. The response of the structure transmits a characteristic signal which is detected by the receiving transducer. Analysis of the frequency content of the response signal yields the resonance peak frequencies, from which the base resonance frequency, and ultimately the structure's thickness, can be estimated.

ART is not dependent on a liquid coupler and hence it can be used in gas pipelines however the use within low pressure pipeline needs to be assessed.

Since ART is a relatively new technique for pipeline inspection there is limited experience in general and no examples of use within CRA pipelines have been published. Within CRA clad/lined pipelines ART is expected to have similar challenges as traditional UT tools which require metallurgical bonding between the CRA layer and the carbon steel if inspection of the full wall thickness is required.

9.1.7 MEC™ Tools

The Magnetic Eddy Current technology is a dynamic electromagnetic scanning technique that combines a direct current magnetic field with an Eddy Current field. It is stated to be the next generation of the SLOFEC technology. The technique is capable of inspecting through different coatings and cladding types and it is claimed that an ILI tool based in the technology is under development.

9.2 External Inspection

External inspection techniques may require removal of coating to expose the pipe surface and access around the circumference of the pipe.

Techniques include, but are not limited to:-

- Ultrasonic Technology (UT) / Time Of Flight Diffraction (TOFD) / Phased Array (PA)
- Radiography (RT)
- Guided Waves (GW)
- Magnetic Flux Leakage (MFL)
- Electro Magnetic Acoustic Technology (EMAT)
- Saturated Low Frequency Eddy Current (SLOFEC) / Magnetic Eddy Current (MEC)
- Acoustic Resonance Technology (ART)

10 Assessment & Repair

Guidance on the assessment of defects in CRA line pipe is not available in PDAM or any other industry codes/standards doing little beyond highlighting the need for special or expert attention. The treatment of these materials, including girth welds, is complex especially when combined with installation methods involving plastic strains. Consequently, effort is now required to develop validated defect assessment procedures for CRA line pipe, which should be included in further updates to PDAM.

The three different types of CRA pipelines; solid CRA, CRA clad, CRA lined; each provide specific challenges for the assessment.

Assessments should include the capability to provide a continued effective barrier against accelerated corrosion in addition to mechanical integrity.

The rate of pit growth is a function of temperature, pH and the presence of chloride ions. Determining the growth rate within CRA pipelines can be complex.

POF has not been able to identify any experience of repairing CRA lined or clad pipelines. This should be addressed in the design phase.

11 Final Remarks

CRA materials have been selected for severe operating conditions due to their increased corrosion resistance when compared to carbon steel pipes. However, to take advantage of its superior metallurgical performance it's paramount to assure high quality levels and commitment in all stages of pipeline life cycle (e.g. material selection, design, pipe fabrication, construction, operation, etc.). When this is not the case some failures may occur. Because of this, and also due to potential challenges that ILI inspection tools for CRA material still face, it's extremely relevant that additional care must be taken during design, fabrication and installation of CRA pipelines in order to avoid potential threats into the pipeline once it is put in place.

Continued dialogue and use of best practices will continue to help improve the understanding and practice of integrity management of CRA pipelines and will help reduce operational risks for Operators. Regular review of the contents of this document together with root cause analysis and lessons learnt from any related pipeline incidents is recommended.

This document highlights some of the issues to be considered whilst developing plans to manage the integrity of CRA pipelines during manufacturing, fabrication, installation and operations. The use of structured inspection, maintenance and repair regimes together with the management and monitoring of operating conditions will minimise the potential for the deterioration of CRA pipelines and the potential for pipeline failure.