INTERNAL CORROSION

Robotic repair of live lines

With many pipelines being kept in service beyond their original design life, the requirement to monitor and, if possible, repair internal corrosion defects is becoming more significant, writes *Stephen Cater*, Principal Project Leader – Friction and Forge Processes, TWI Technology Centre.

Internal defects in pipelines are difficult and costly to repair, especially for subsea lines. Yet even these costs are small in comparison with the loss of revenue that ensues if it is necessary to close a pipeline while a repair procedure is performed.

Corrosion within a pipe can arise from many sources, in both sweet and sour conditions. The main factors are the interplay of entrained water, acids and bacterial activity. The rate of corrosion can vary greatly and is influenced by the presence or absence of protective coatings, turbulent flow, generation of passivating corrosion products, use of corrosion inhibitors and the maintenance regime of the pipe.

Modern pipeline inspection gauge (PIG) systems are capable of detecting the onset of corrosion and monitoring its spread, providing valuable data on the location and potential consequences of the problem. However, once the presence of a defect is known there is a requirement on the operator to assess and mitigate against any effects it may have. Existing means of dealing with corrosion or similar small defects are considered in **Table 1** – almost all are complex, expensive or difficult to deploy, and usually require significant time to implement.

Early intervention

Being able to intervene early and repair any internal corrosion damage discovered before it necessitates a reduction in operating pressure or pipeline closure is desirable. Ideally this requires a repair technique that is deployable inside the pipe, and which does not require the system to be drained for the repair to be made. Conventional welding techniques, for example arc or laser welding, cannot be used in an operational pipeline, while the use of epoxy grout and internal liners requires that the pipe be clean and warm when the repair patch is applied.

With these limitations in mind, The Welding Institute (TWI) was asked to investigate the feasibility of deploying a friction stir welding (FSW) system to facilitate an in-situ repair on a live pipeline.

Friction stir welding study

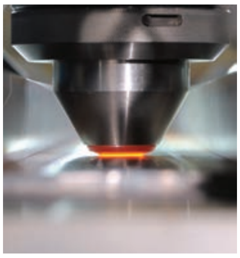
Friction stir welding is a solid state welding process that literally joins metal components by stirring them together at the joint line. In FSW, a rotating tool presses into the components to be joined and generates enough frictional heat to soften or plasticise the metal without melting it. This soft metal is then swept across the joint line, forged together and consolidated to give a very strong, tough, fatigue and corrosion resistant weld. FSW can operate underwater, is a mechanised process amenable to robotic control and does not create a flammability hazard.

The idea, termed FSWBOT, received funding from UK Innovate in 2018 for a consortium led by Forth Engineering to develop a 'proof of concept' system. This system will demonstrate that a patch weld can be made in steel pipe under oil, and that a representative FSW system can be made small enough to operate in a 36-inch diameter export pipe.

A number of technical difficulties needed to be overcome, not least of which is that FSW requires friction to operate and oil is rather good at eliminating friction. FSW welding machines also tend to be rather large as a consequence of the forces required to plasticise and forge steel. So, making a machine capable of moving through a 36-inch diameter pipe, perhaps for several tens of miles, and then performing a repair weld, also presented a challenge. Similarly, the machine is required to operate autonomously at the repair site, and to have sufficient energy to perform the weld, inspect it and then move on.

Design brief

Under the design brief, the first system should be capable of autonomously repairing 40-mm diameter corrosion defects at the six o'clock position whilst the pipeline is still operational. The FSWBOT is currently envisaged to be a five- or six-segment PIG type vehicle which will be inserted at the production end of the pipeline and will travel with the oil flow to a pre-designated spot to perform a repair. One segment will carry the FSW machine and a steel patch dispenser, with the other segments carrying the navigation, control system, communications, NDT (non-destructive testing) and power storage/generation payloads.



Friction stir welding is a solid state welding process that generates enough frictional heat to soften or plasticise the metal without melting it, allowing metal components to be forged together at the joint line
Photo: TWI

On entering the pipe segment containing the pre-identified defects, the FSWBOT will stop, then slowly advance until the FSW system is in place over the defect. It will then lock itself in place and confirm that it is correctly located to perform the repair. An onboard turbine in a duct within the FSWBOT will harvest energy from the oil flow within the pipe to augment any power cells carried on the system, with the duct providing through flow in the pipe.

Once energised, the FSW unit will deploy a milling tool to cut away the corroded area and prepare a pocket in the pipe wall into which a steel patch will be dispensed. The

EI corrosion management guidance

A new fully updated *Guidance for corrosion management in oil and gas processing* has been published by the Energy Institute, equipping the oil and gas industry with the necessary good practice tools to address corrosion.

The publication was launched earlier this year at the Aberdeen Exhibition and Conference Centre (AECC), accompanied by a programme of presentations from both industry and the regulator. The programme included presentations setting out the path that the EI took to update and expand the guidance document, highlighting how it tied in with elements of the HSE HSG65 model and the CAN-DO-CHECK-ACT approach, which in turn was recognised by HSE co-badging acknowledging the new document as an approved source of industry good practice guidance for effective corrosion management and control.

However, corrosion never rests and with an estimated 2–4% of an operator's turnover[1] lost to corrosion, the mission continues to actively chase the estimated 25% that can be saved. The EI maintains a full suite of evolving documents that helps the oil and gas industry worldwide to manage what is an omnipresent and unrelenting foe. ●

1. *Guidance for corrosion management in oil and gas processing*, 2nd ed, 2019. The Energy Institute

Repair strategy	Advantages	Disadvantages
Monitor and reduce flow	Quick and easy implementation No immediate repair cost	Reduces product delivery rate Does not eliminate the defect
Type A sleeve	Proven technology with a service record Moderately simple to apply on land	Will not contain a leak Requires welding – difficult for subsea pipes Difficult to inspect No axial strength
Type B sleeve	Proven technology with a service record Moderately simple to apply on land Will contain a leak	Requires welding – difficult for subsea pipes Difficult to inspect Fillet weld at sleeve end is complex and a frequent source of further defects The sleeve is welded to the pipe, which can be difficult at low temperatures Limited axial strength
Stand-off shell	Proven technology with a service record Moderately simple to apply on land Can be fitted to bends	Requires welding and complex fabrication – difficult for subsea pipes Difficult to inspect Has welding problems at low temperatures and high flow rates Limited axial strength
Epoxy filled sleeve	Proven technology on land Moderately simple to apply (on land) Can be load bearing Can be affixed with flanges rather than welding	Not proven at sea Difficult to inspect
Conventionally welded external patch	Proven technology on land Moderately simple to apply on land Can be load bearing Can be affixed with flanges rather than welding	Requires welding – difficult at sea Difficult to inspect Fillet weld is often a source of further defects Cannot be performed internally on a live pipe
Mechanical clamp	Proven technology with a service record Moderately simple to apply on land Will contain a leak	Generally a temporary fix as seals degrade over time Frequently requires welding to the pipe to enhance performance – difficult at sea Heavy and difficult to handle Often a bespoke part
Internal liner	Permanent May be possible to deploy the liner internally Can cover extensive corrosion	Pipeline must be taken out of service and cleaned Can be difficult to inspect and conceals underlying corrosion Ends of liner must be sealed Concerns over sour service
Line or section replacement	Permanent Allows for redesign or material improvement to resist further corrosion	Expensive Very time consuming

Table 1: Potential repair or mitigation strategies for internal pipeline corrosion *Source: TWI*

FSW unit will then weld this patch in place and deploy the milling system again to ensure that the patch is flush with the pipe wall and will not initiate turbulent flow, nor impede the passage of subsequent cleaning or inspection PIGs.

FSWBOT will then deploy NDT packages to inspect the weld for quality assurance before unclamping and moving downstream to repeat the process on any further defects.

Project progress to date has been good, with the following key milestones achieved:

- The feasibility of friction stir welding under oil has been demonstrated.
- Initial assessments have shown that the welds are sound and do not change the composition of the welded metal.
- The basic design of the system and its power requirements have been established, enabling detail design and specification of the onboard systems to begin.

The project is now moving forward to build a demonstration prototype, which is to be tested in a simulated pipeline in 2020. If successful, FSWBOT, will offer the following advantages over existing techniques for subsea pipeline repair:

- Can be deployed inside an operational pipeline using existing PIG launchers.
- Does not require the pipeline to be cleaned and gas purged.
- Will perform a load bearing, welded steel repair at multiple sites in a single pass through the pipe.
- Will provide quality assurance (QA) data on repair quality.
- Will not induce turbulent flow or create a gauge restriction.
- Can be deployed relatively quickly without the need for ships and diving support.

The FSWBOT system will allow for effective repairs to be made in previously inaccessible, or difficult to access locations, more quickly and cheaply than other techniques, and with fewer consequential effects. Further developments have been discussed that would allow similar systems to be used on free-swimming robots to perform external repairs on a variety of structures, including production platforms, onshore hydrocarbon storage tanks and internal ship tanks.

Further details of the FSWBOT project can be found at **www.fswbot.com**