Corrosion Management
Issue 153 January/February 2020

Transmission Pipelines

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This publication is Recyclable.
Welcome to the first issue of 2020, and the first to show the new Institute logo. Also the front cover shows the winner of the Institute photo competition to find a new image to reflect the industry we are in. As has become usual, there are three technical articles, with two covering different aspects of pipeline corrosion protection, and the third a look at what the future holds for painting ships. Firstly, an article from TC Energy in Canada about the suitability of stored FBE coated pipe segments to be used in a gas transmission pipeline, and secondly, a look at pipeline integrity management from Australia. The third article looks at the areas where coating technology developments will be needed to meet the challenges of protecting ships in the future.

There are also two new columns, which will be a regular feature if the magazine – a Fellow’s Corner, where senior members of the Institute highlight their experiences and offer practical advice, and a Question & Answer column, where readers’ questions are answered by industry experts.

I would appreciate reader’s comments on these new columns, and you are invited to submit technical (generic) questions for consideration.

I can be contacted at, brianpce@aol.com

Brian Goldie, Consulting Editor
New Members

Welcome to our 216 new members and 15 Sustaining Company members who joined the Institute in 2019.

TECHNICIAN
• Toni Gordon
• Robin Isaac Wilson
• Shaun Scholes
• Craig McCann
• Matthew J Grindrod
• David Belfield

PROFESSIONAL
• Mahmoud Hasan Daghestani
• Keith M Wagner
• Ricardo Ocampo Ramos
• Yousef Abdulrahman Obeid
• David Wright
• Bilal Ahsan
• Mahesh Panchal
• Man Mohan Wagheya
• Syed Umair Naiz Bukhari
• Tarek Hamada Farghaly
• Barakhkumar Krishnan
• Mohamed Saad Eldieb
• Emmanuel Alenkhe
• Ahmed Shakif Badawy
• Luigi Petrone
• Ali Attia Abdel Razek
• Aqeel Ul Qadar Ahmed
• Mohamed Mohamed Mukhtar
• Nigel Ratcliffe
• Jaison Wilson Lobo
• Thamizhanthan Dhanapal
• Hugh P O’Neill
• Fahad Muhammad
• Ahmed Magdy Wahba Mahgoub
• Naveed Hassan
• Muhammad Umer
• Jonathan Wilmshurst-Smith
• Prakash Shanmugam
• Nigel John Owen
• Irving B Annan
• Agnieszka Knyter
• Mohammad Faraz Muslim
• Zucjia Liu
• Gregory Brown
• John Stephen Rae
• Ahmed Amin Abdul-Rahman Ali
• Mahalingam Ganesan
• Santhosh Nagarajan
• Richard Barker
• Kevin Harold
• Tamer Ibrahim Ahmed Mohamed
• Danny Burke
• Sherif Abdel Hamid Helmy
• Syed Sajid Ali Qadri
• Mohamed Fawzy Mohamed Omar
• Mustafa Hashim

FELLOW
• Nigel David Strike
• Kupplili Prabhakara Rao
• Mohammad A Al-Anazi
• Marcello Angelo Biagioli
• Emmanuel Marcus
• Basanta Kumar Lenka
• Aftab Fakhruddin Khan
• Yunnian Gao
• Joseph Itodo Emmanuel
• David Horrocks
• Richard Green
• Sarah Vasey
• David W Harvey

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www.Rustrol.com

Young Engineers Programme (YEP)

The latest Young Engineer Programme kicked off on the 8th January and was held at the same venue and time as the London branch meeting. Bill Hedges gave an introduction to the programme, and a review of YEP 2018 was given by participants Caroline Allanach and Stephen Shapcott, all coordinated by Alan Denney. This year there are 32 young engineers taking part, compared with 14 in 2018. This is a clear indication that the industry is healthy and on a growth spurt.

The first talk was given by Dr Jane Lomas, and dealt with the “Basics of Corrosion” as the lead into the series of nine lectures throughout the year. The programme will culminate on 12 November when the YEP candidates will present their solutions to the case study at the London branch meeting at the Royal Overseas.

The young engineers then had time to talk to the established engineers attending the LB meeting over refreshments.
ICATS News

Mr Steve Barke, the Managing Director of CORREX (which manages the ICATS programme), retired in December 2019 after several years at the helm. Steve took up the reigns at CORREX during a time of change and created much needed stability and new enthusiasm during this most important phase of ICATS. Kevin Harold, was appointed as the new MD effective from 1st January 2020, and Steve will remain on the CORREX board and continue to help during 2020.

Towards the end of 2019, meetings were held between CORREX, IMechE and Hodge Clemco, which culminated in the creation of a new ICATS ‘Approved Training Centre’ in Sheffield. The ICATS courses will be delivered in Sheffield starting early 2020, with the theoretical aspects being taught at IMechE and the practical aspects of the courses held two miles down the road at the equally superb facilities of Hodge Clemco. I think you will agree as a collaboration this has the ‘hallmark’ of quality written all over it.

ICATS Apprenticeship Update

The new Industrial Coatings Apprenticeship scheme started at the beginning of 2019 with CORREX (ICorr) providing the technical information, DN Colleges supplying the mandatory apprentice information and Jack Tighe would deliver the whole package. This was the first Industrial Coating Apprenticeship ever (in the UK).

Training continued throughout 2019, with a second wave of students started training during the summer of 2019. The first students will complete their apprentice training in May/June of 2020 and our industry will have the first ever qualified, industrial coating applicators apprentices.

Corrosion and Protective Coatings Management, CPCM course

The CPCM course (previously the ‘managers course’) was launched in 2019. It was created for managers and engineers or anyone involved in management of protective coating applications, but who didn’t have the best understanding of what the Industrial Coating Applicator, ICA, was really doing. The one-day course takes attendees on a journey of the ICA and includes, H&S, preparation techniques, ISO standards, paint technology and paint faults. The course has been presented a number of times during 2019, and in fact has proved so popular that it is soon to be mandated for all trainees and apprentices at the Sellafield Nuclear Facility, thereby bridging the gap between management and applicators. By the time this issue goes to print the latest course would have been delivered, exciting times.

The ICATS Family

ICATS continues to grow in the UK, with new companies joining, new trainers teaching, many more safe applicators on our projects, plus three new approved training centres in 2019.

ICATS has some representation overseas, but the family is about to grow with our delivery partner, IMechE, who have global distribution of many courses that includes Painting Inspection and NDT testing. IMechE will be expanding the ICATS family on a global basis during 2020 under the direction of Director Mr Chris Kirby and his team in Sheffield.

Dates for your diary

For those requiring a company trainer certification, the next ICATS Company Trainer Course will be held on 31st March - 1st April at Corrosion House, Northampton. This course teaches presentation skills, tests knowledge and demonstration of the ICATS ICA, Industrial Coating Applicator course and the ICATS Sprayer and Blaster specialist modules.

The next Supervisor course is on the 25th and 26th of February at Corrosion House. The supervisor course is now mandated in many places/industries including Highways.

Finally, the next Corrosion and Protective Coatings Management course (CPCM) is on the 2nd of April, also at Corrosion House.

Up-to date course information can be found at www.icats-training.org/

Corrosion Engineering Division working day

The 2020 Corrosion Engineering Division working day meeting will be held at the National Railway Museum Conference Centre, York, on Wednesday 29 April 2020, on the subject of ‘Corrosion Control in Transport and Infrastructure’. The meeting will follow the normal format of a series of invited lectures combined with working group meetings, and the presentation of the Paul McIntyre award to the 2020 winner. There will also be an opportunity to view the impressive range of vintage steam engines in the museum. An information and registration leaflet is included in this issue of Corrosion Management, and exhibition space will be available for hire.

New Sustaining Member

DEV4 Online Ltd

Dev4.online have been working with Engineering companies across the globe since 2004, designing and building bespoke software applications. They are the custodians of www.CONDI.online, which is a web application for managing corrosion on large structures, such as oil rigs, vessels and bridges. CONDI was designed with the collaboration of many companies in the oil and gas industry who have a wealth of experience in external corrosion management, and was built by a team of software developers who have worked predominantly in the corrosion industry over the last 10 years.

Visit the ICATS website

www.icats-training.org
New Sustaining Member

Hodge Clemco Ltd

Hodge Clemco Ltd is a UK based manufacturer and supplier of blast cleaning machines, surface preparation equipment and abrasives. They have two manufacturing sites in Sheffield for both equipment and abrasives, and an extensive distribution and stockist network. Hodge Clemco’s wide manufacturing and service capability includes; portable blast machines, expendable and recyclable abrasives, plastic and Envisponge media and equipment, blast room installations, grit recycling systems, bespoke engineered solutions, blast cabinets, PPE and spares, servicing and training.

Incorporated in 1959, Hodge Clemco have developed into a market leader in the surface finishing industry. Their products are used every day in many prestigious installations for the Ministry of Defence, Lockheed Martin, BAE, BP, Shell and Rolls Royce, to name but a few. Part of the 110-year-old Samuel Hodge Group, Hodge Clemco is part of a diverse engineering group which includes Techniquip, Victor Marine and RLBS.

ICorr Photo Competition

As has already been announced, the Institute has a new image and this will involve rebranding of the website, stationery, documentation and marketing material, and of course this magazine. To help with this new image, the Institute launched a photo competition to find images that are people-focused and celebrate the people that make ICorr, or capture a wide range of activities, such as people networking, working on-site, people in labs, people inspecting, or people achieving accreditations and awards, rather than tired-looking images of rusty components previously used. The designers were looking for uplifting photos of pristine, gleaming infrastructure to emphasise that our members get things right!

The winning photo of an under-deck inspection on an offshore wind turbine jacket, picked by a panel of ICorr judges, was submitted by Simon Dunn, Dangle Ltd, and is featured on the cover of this issue of the magazine. It will also feature on the landing page backdrop of the rebranded website.

Local Branch News

The local branches offer a great opportunity to meet and network with others in the corrosion protection industry, and the technical presentations and seminars are an excellent way of keeping informed of the latest developments in corrosion mitigation, as well contributing to an individual member’s professional development requirements, which are an essential requisite for those seeking and maintaining chartered status. The local branches need your support, and on this subject, North East branch is looking for a new chair person – if you are interested in this, please contact: icorrne@hotmail.com

The latest reports from the various branches are given below.

Aberdeen Branch

The branch held its 4th event of the 2019/2020 session at its usual venue, RGU, with a presentation on “The Application of bismuth based alloys to address Oilfield challenges” by, Paul Carragher (BiSN), Lance Underwood (BiSN) and Angus MacLeod (BP).

This was a highly successful joint presentation with IOM3 – The Institute of Materials, Metals and Mining, which has recently celebrated its 150 year anniversary.

The BiSN speakers discussed in detail their Wel-Lok sealing technology which utilises a unique combination of a thermite powered chemical heater and a bismuth based alloy to deliver an efficient down hole sealing capability, using standard oilfield deployment methods.

The thermite heater provides the energy to melt the bismuth alloy in situ, allowing the heavy liquid alloy to flow by gravity to the desired location. As the bismuth alloy cools, it expands on solidification to provide a seal.

Paul Carragher started BiSN in 2010 with the insight to develop new and innovative sealing solutions for the oil & gas industry, and explained the use of bismuth in downhole sealing applications.

Lance Underwood, Principal Engineer at BiSN Oil Tools, who has has over 30 years of experience in the industry, then provided further insights into the development of new technologies for plugs for oil wells, covering materials selection, downhole corrosion control and long-term corrosion testing programmes.

He illustrated some of the rigorous testing requirements for downhole oilfield tools including bits, mud-motors, turbo-drills, under-reamers, hammers, and laser drilling.

Lance Underwood, explained the extensive Corrosion Testing Programme.

Angus MacLeod (Senior Intervention Engineer with BP), with 22 years Oil and Gas industry experience, then followed this up with some actual case histories from BP operations worldwide, where this technology has been continues on page 8
Angus MacLeod highlighted the many practical applications for this new Downhole Sealing Technology.

applied offshore, to shut off water production in open-hole gravel pack completions, as well as the work being done to qualify the alloys, as a permanent well abandonment material.

In his current role, Angus is responsible for developing new well technology as part of BP’s Upstream Technology Group, primarily focussed on “Life of Well Surveillance” and “Plug & Abandonment”.

The event generated a huge level of interest and many questions were asked, which can be found, together with the answers, on the branch website.

The Aberdeen Chair Stephen Tate, presented all speakers with Certificates of Appreciation.

At the close of the meeting, the branch chairman, presented all speakers with a Certificate of Appreciation from the branch.

Full details of future branch events can be found on the diary page of this magazine and on the website, or by contacting: ICorrABZ@gmail.com.

Copies of the majority of past branch presentations can be found at: https://sites.google.com/site/icorrabz/resource-center and a photo gallery for these events is at, https://sites.google.com/site/icorrabz/event-gallery

Particular attention is drawn to the 2020 Corrosion Awareness Day to be held on Tuesday 25th August at, Petrofac Training Centre, Forties Road, Montrose, Angus, DD10 9ET. The day will include several practical demonstrations with teaching, this year themed on fabrication and external corrosion management. Further Details about this can be obtained from the branch Chair: Stephen Tate, email: Stephen.Tate@external.total.com

Visit the ICATS website www.icats-training.org

London Branch

The 2019 branch luncheon proved to be another great success, as the audience was bowled over by an enthraling guest appearance from legendary cricket commentator Henry Blofeld OBE. The unmistakable voice of the Test Match Special, regaled the crowd at the Royal Overseas League in Mayfair with stories from his 45-year career behind the mic, and his two books, which he happily signed for guests after the lunch.

Before the 170 guests settled in the Hall of India and Pakistan for the afternoon, the branch team of diligent raffle sellers had time to mingle and raise an approximate £1,650, which will help fund the future branch series of evening lectures.

The contribution from Henry was greatly appreciated, as was the involvement of the event’s sponsors, which this year included Winn and Coles, DuraPol, Corrosion Integrity Management, Correx, and CTS.

The annual event also gave guests the opportunity to reflect on those that the industry lost this year, and in particular the passing of Bill Cox. Tributes to him were led by Institute President Gareth Hinds, who gave a superb account of the excellent work that Bill had done for the Institute during many years of service, which culminated in a rousing applause that Bill would have undoubtedly appreciated.

Preparation has already begun for the 2020 Luncheon, as well as a possible summer ball in London 2021, which will celebrate the 25th anniversary of the of the change of name of the Institute from the British Association of Corrosion Engineers (BACE) in 1966 to the Institute of Corrosion Science & Technology , which was the forerunner of the current Institute of Corrosion.

The first meeting of the branch on Wednesday 8th January had 40 attendees and started with an introduction to the new branding concepts for the Institute, which will be launched in February this year, given by Marc Desmeules, who gave a fascinating insight into the process behind designing a new logo which was the start of the rebranding exercise.

The main technical meeting followed which was a panel discussion on the complexities of internal linings, the selection variables and the link to design standards. The first presentation was from Dr Nasa Miskin from DuraPol who gave a presentation on “Corrosion Prevention in Acid Gas Treating Units”, an extremely difficult and complex environment for any lining system. This was followed by a presentation from Simon Daly of Hempel on “Internal Linings; Selection Variables and Link to Design Standards” which culminated in a discussion on the requirements for the new ISO standard for the internal lining of process vessels.

Both presentations are available to view on the Institute of Corrosion website.

The March meeting will be the branch AGM, followed by the chairman’s talk.

Please note the date, Tuesday 10th March.
William Michael (Bill) Cox  
(14 Apr 1950 - 3 Dec 2019)

I first met Bill shortly after I joined the UMIST Corrosion and Protection Centre in 1983. I had been interested in corrosion sensors for detection of hydrogen, and had several discussions with him about the feasibility of the various available corrosion detection methods (mine was useless!). He always focussed on the argument that there was no point knowing whether corrosion was happening unless you also were prepared to intervene to manage the corrosion process. However, at the time industry was more interested in repair after failure rather than management of the processes leading to failure. Of course, being 10-15 years’ ahead of the game Bill was exactly right and over his career he became one of the leading figures in risk and asset management of plant where corrosion is generally the dominant failure process.

Born in Keithley in Yorkshire, Bill was a boy soprano and chorister, he played the piano and the guitar, he was a keen motorcyclist and owner of a vintage BMW K100RS, a very devoted family man, and a serial speeder in either of his two elderly Audis. He completed his undergraduate studies in metallurgy on a sandwich course at the University of Aston in Birmingham in 1975 during which time he met the ‘girl’ who was later to become his wife. On completion of the programme he went to work at the copper-nickel smelter in Selebi Phikwe in Botswana. He later to become his wife. On completion of the programme he went to work at the copper-nickel smelter in Selebi Phikwe in Botswana. He loved working with hot metal and the problem solving involved with developing the plant in harsh working conditions.

In 1978 he moved back to the UK to study for an MSc in Corrosion Science and Engineering at the University of Manchester Institute of Science and Technology (UMIST) and in the same year married Anna. After completing his MSc he stayed on to undertake a PhD with John Dawson on “Acid Dewpoint Corrosion”, a problem that was beginning to become of significant commercial concern particularly in power generation and steam-raising plant. Graduating in 1981, he linked up with the Corrosion and Protection Centre Industrial Service (CAPCIS) to develop expertise in, and to market, risk-based inspection and risk based maintenance technologies for the process industries, as well as general failure investigation and litigation work. His client base was worldwide with projects in Europe, North America and Pacific East Asia.

A strong supporter of ICorr (as Member of Council and of the Training and Certification Board for 20 years and President from 1996-98), IOM3 (as Member of Council from 1993-2003), BINDT (as member of the PCN Certification Board) and NACE (as both Member and Chair of its International Relations Strategy Operations Committee) and was a Fellow of all of these Institutions, the last being a singular Honour. As well as attending (and organising) many conferences, seminars and publishing more than 32 papers, Bill also found time to act as Technical Advisory Editor for Anti-Corrosion Methods and Materials for over 10 years, significantly increasing the journal’s profile.

Well known for his eponymous number plate “B111 COX”, acquired after a nudge from Les Woolf, Bill directly launched and influenced the careers of many people now in senior positions in the corrosion industry. He was always generous with his time and was ever willing to provide advice and mentoring to anyone who asked. Creditably, he always did what he said he would do with energy and enthusiasm, he was a well-attended meeting. Bill Whittaker, bwhittaker@cathodicengineering.co.uk, or Paul Segers, paul.segers@segcorr.com

For any branch queries, please contact Bill Whittaker, bwhittaker@cathodicengineering.co.uk, or Paul Segers, paul.segers@segcorr.com

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The President makes the news

In an article in The Times (Friday 17th January 2020) on the use of hydrogen as an alternative fuel for cars, the ICorr President, Gareth Hinds, who works on hydrogen technology at NPL, was quoted. Gareth noted that electric vehicles alone are not a magic solution to reduce carbon emissions and that hydrogen fuel also has a role to play. He also noted that the use of hydrogen fuel cells is more suitable for heavy vehicles and longer distances, making them a good option for freight transport.

Research news - Smart Patch Can Help Reduce Rust

Aarhus University, Denmark, has announced that researchers from its Department of Engineering’s ICELab are developing a new, intelligent and self-powered sensor to monitor rust found on steel reinforcement within concrete infrastructures.

The project is being conducted in collaboration with IdemoLab, at the technological service company FORCE Technology, Brøndby, Denmark, and is being funded by Innovation Fund Denmark.

According to Aarhus University the current corrosion sensors used for rust monitoring are “indicative” and “energy-demanding” in addition to being dated, error-prone, and costing up to roughly $5,500 per measuring point. In an effort to update the aging technology, Associate Professor Farshad Moradi from the University’s Department of Engineering has established project DIGIMON, which aims to develop smart, self-powered patches for updated corrosion monitoring.

The aim of this project is to develop a plaster sensor which is placed on the reinforcement and moulded into the concrete construction. The sensor and interfacing electronics will be powered by means of energy-harvesting technologies to ensure continuous monitoring of the condition of the steel.

Moradi further explained how the plaster sensors will work, describing that once developed, the sensors would use ultrasonic waves generated locally in the self-powered sensor inside the concrete to monitor the corrosion. Once information is collected from the developed plaster sensors, it would be sent to a central computer to be processed.

Coatings technical conference

ETCC2020 – the European Technical Coatings Congress, organised by FATPEC – Federation of Associations of Technicians for Industry of Paint in European Countries, and SITPChem – Polish Association of Chemical Engineers will take place on 2–4 September 2020 in Krakow, Poland.

ETCC2020 is one of the most prestigious and important technical and scientific coatings events, creating a platform and a meeting point of industry and science, represented by institutes and universities. The congress creates the possibility of international co-operation and collecting unique knowledge about the newest materials, products, processing, equipment, research and testing. The Congress has 70 years of tradition and will cover the latest scientific and technical achievements in paints, coatings, adhesives and construction materials.

During the three days of the event there will be plenary presentations, 3–4 parallel sessions, poster presentations, and an exhibition. A “Summer School” with lectures dedicated especially for young scientists and students forms a separate part of the congress.

The speakers represent the largest companies, institutes, and universities across Europe, as well from other countries world-wide.

Further information can be found on the congress website, www.etcc2020.org

Welding robot set to ‘revolutionise’ pipeline repair

Forth Engineering, a Cumbrian engineering company is leading the development of a welding robot to repair pipelines from the inside. It is being described as a ‘world-first pipeline technology that will revolutionise performance and safety in industries around the world’.

The FSWBot is a friction stir welding robotic crawler for internal repair and refurbishment of pipelines, which is being developed by a consortium led by Forth Engineering in Cumbria with UK government backing. The consortium includes TWI, J4IC, Innvotek and London South Bank University. The development project is due to be completed by end of January 2021.

According to the company, the FSWBot is envisaged to be a five-segment or six-segment PIG type vehicle which will be inserted at the production

PRA Training Courses

Paint Technology course on 9th – 12th March 2020

This course is designed for newcomers to the industry who need a firm foundation in the technology of surface coatings. The comprehensive and intensive four day course will contain an overview of the raw materials used, and their contribution to the final properties of the coating.

Further details can be found at www.pra-world.com
end of an oil 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, non-destructive testing (NDT) and power storage/generation payloads.

On entering the pipe segment containing the pre-identified defects, the robot 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 robot 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 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.

Corrosion under Insulation Course

This advanced training course, based on the original CUI training material written by Stefan Winnik, and organised by Fleming Events, will held on 12-13 May 2020 in London, and presented by Dr Clare Watt, Keafer Isoliertechnik, and Dr Steve Paterson, Arbeadie Consultants. The key topics will include, understanding the key characteristics of CUI and its management, insulation and coatings, innovative technology, case studies, and an overview of the latest guidance.

More information can be found at, https://fleming.events/corrosion-under-insulation/

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Hydrocarbon producing facilities are potentially subject to both external and internal corrosion threats: in the case of the former, from hostile and geographically remote operating environments, and in the latter from the presence of wet produced fluids and acid gases. Both of these threats continue to impact materials selection, engineering design and through life integrity management. Selection and optimisation of appropriate materials, which can tolerate given production scenarios together with effective whole life corrosion management, remain key operational challenges and underpin successful hydrocarbon production, economy, safety and security. Correct choice of materials and their optimisation in such systems at the design stage is therefore an essential element of an effective corrosion management programme to achieve high reliability and trouble-free operation. The choice is governed by a number of principal parameters including adequate mechanical properties, corrosion performance, joining integrity, availability and cost.

This Fellow’s Corner gives an outline of a materials optimisation strategy by combining a number of these key ingredients. It takes advantage of materials with proven track record while describing attributes essential for such a holistic approach. It focuses on internal corrosion by produced and injected fluids as the principal criteria in materials selection. While descriptive, a basic of knowledge of materials and corrosion is nevertheless, highly advisable so that a fit for service solutions is achieved. Amongst the parameters outlined above, two elements are elaborated further.

i. **Corrosion Threats:** given the conditions associated with hydrocarbon production and that of gas/water injection, internal corrosion must always be seen as a potential risk. The risk becomes real once an aqueous phase is present and able to contact the material, providing a ready electrolyte for the corrosion reaction to occur. The need to reliably handle wet hydrocarbons arises from the increasing number of fields where significant levels of CO₂ and H₂S are present under more arduous operating conditions. In addition, the growth in the need for increased production which invariably entails water and/or gas injection to maintain reservoir pressure and/or enhance recovery can introduce O₂ and the potential for microbiological activity which presents a different type of corrosion threat.

While most classical forms of corrosion are encountered in hydrocarbon production, the principal types where the majority of failures occur remains limited. The most prevalent types of damage encountered include metal-loss corrosion and localised corrosion manifested in the presence of CO₂ (sweet corrosion) and H₂S (sour corrosion) dissolved in the produced fluids and by the presence of dissolved oxygen in water injection systems. These three types of corrosion threat should be addressed specifically in the material optimisation process when assessing corrosion risk. In addition, the potential risk of environmental induced cracking needs to be addressed effectively.

ii. **Metallic Materials:** The oil and gas industry sectors continue to lean heavily on the use of carbon and low alloy steels (CLAS) which are readily available in the volumes required and able to meet many of the mechanical, structural, fabrication and cost requirements. The technology is well developed and for many applications these materials represent an economical choice. However, the inherent corrosion resistance of CLASs is relatively low. Consequently, their successful application invariably requires combination with one or more whole-life forms of corrosion mitigation against both internal and external exposure conditions.
The simple overall approach to the optimisation strategy, shown in the figure, captures these necessary steps in finalising the materials choice. This simplified roadmap includes several key elements taking on board and incorporating (i) corrosion risk evaluation, (ii) operating conditions, (iii) corrosivity assessment, (iv) erosion velocity, (v) window of application of individual alloy, and last but not least (vi) whole life costing of potential materials options and corrosion mitigation methods. The simple methodology is based on utilisation of past successes and lessons learnt in effective use of CLASs and integration of key parameters to allow the selection of the most suitable, safe and economical material option and corrosion control measures.

The roadmap follows a methodical route to highlighting options and the most appropriate and cost effective materials, and outperforms similar models through the unique integration of key parameters. The strategy is applicable to optimisation of materials for all applications including downhole completions, surface and transportation facilities.

A distinction should be made here between materials used for subsurface (wells), where welding and CA may not be applicable, in contrast to materials for above surface facilities (subsea, topside or transportation) where corrosion mitigation in the form of CI deployment, or CA, become feasible.

Throughout the process, in the absence of reliable data, a methodical approach to performance evaluation needs to be put in place and be implemented. This provides a flexible structure to allow realistic testing to enable input of complementary data to provide further confidence on their application.
Zinc-rich primers are commonly used for the protection of structures exposed to severe environments. The level of zinc dust is classified by the weight of zinc in the dried film, and most standards and specifications require at least >77% to meet the performance demands. In conventional zinc-rich epoxy primers the high levels of zinc are achieved by adding large amounts of zinc dust particles into an epoxy matrix and the dispersion of this is critical to ensure electrical continuity and hence galvanic protection of steel.

I have heard of zinc epoxy primers on the market with considerably lower zinc levels (as low as 31% by weight). Do these primers still provide good galvanic corrosion protection and maintain good adhesion and mechanical properties of the dried film? **PF**

**Answer:**

Corrosion protection paints using metallic zinc dust as a protective pigment have been used successfully for many decades. Zinc levels in coatings are classified by various standards bodies; common examples being:

- ISO 12944 = “zinc rich” >80% (Zinc dust on dry film)
- BS5493 = “zinc rich” >95% (Zinc dust on weight of pigment)
- BS4652 = “zinc rich” >85% (Zinc metal on dry film)
- SSPC Paint 20 Specification

Type 1 - Inorganic zinc rich paints (Zinc silicates)

Type 2 - Organic zinc rich paints (Epoxy or other organic binders)

- “zinc rich” Level 1, ≥85% (Zinc dust on weight of dry film)
- “zinc rich” Level 2, ≥77% to <85% (Zinc dust on weight of dry film)
- “Reduced zinc” Level 3, ≥65% to <77% (Zinc dust on weight of dry film)

Metallic zinc can protect ferrous substrates via several mechanisms:

- **Galvanic protection** – Fundamental physical chemistry dictates that if two different metals are in intimate electrical conductive contact, the more reactive metal will form the anode in a corrosion cell and preferentially react with the external environment. In the case of these reduced zinc primers, there is insufficient zinc to give true galvanic protection or extensive zinc salt formation and plugging of large corrosion cells, as in extremely corrosive environments such as offshore and marine. These products can however provide effective protection in less demanding environments by means of their barrier and pH buffering mechanisms as described above.

There is no official minimum level of zinc in a reduced zinc primer, although the performance levels will need to be carefully assessed to meet the appropriate specification requirements. Very thin film (~15µ dr) inorganic weldable primers are used on a widespread basis in production of steel stock. These will require very low levels of zinc (sometimes around 15%) in order to meet the required low levels of zinc fumes generated by subsequent welding processes. These products are only designed for temporary protection prior to fabrication.

Formulation of an effective zinc rich or reduced zinc primer requires a high degree of effort (or luck!) on the part of the formulator – It is not just a case of putting in a high loading of zinc and hoping for the best. The higher the zinc loading, then various factors such as poor application properties, weak, powdery film, poor adhesion and importantly, higher cost will have to be considered. A good zinc rich or reduced zinc primer will provide the correct balance of performance in the designated environment, good spray characteristics, compatibility with subsequent coats of paint, all for an acceptable price – Not an easy task! **MM**

**Question:**

With the advent of high quality three layer polyolefin pipeline coatings and liquid or heat shrink field joint coatings having similar corrosion barrier characteristics, current densities for Cathodic Protection (CP) have been greatly reduced. These coated pipelines when in the presence of high voltage overhead power transmission systems tend to experience high induced a.c. voltages as well the possibility of phase to ground faults, which can create a ground potential rise and damage the coating and pipe steel. To provide personnel safety and to protect pipeline integrity induced a.c. and fault a.c. mitigation is required. When such mitigation measures are installed they often take the form of electrical grounding using liner electrodes of zinc or copper connected to the pipeline via d.c. decouplers, where these decouplers proliferate due to the design requirements they can adversely affect the operators’ ability to undertake close interval potential surveys (CIPS) due to capacitor discharge. This discharge supports what should be the IR free potential during the rectifier off cycle thereby providing erroneous and misleading results.

Given this issue what can be done to ensure the pipeline is correctly protected and can the situation be controlled such that CIPS may be carried out, and if not what are the alternative technologies which will prove assurance that protection has been attained? **AN**

**Answer:**

Decouplers on well-coated pipelines can affect off potential readings during CIPS testing. The engineer measuring the results may witness irregular OFF potential waveforms at or near to where decouplers are installed. Most notably the OFF values will be excessively and uncharacteristically negative, and where there are multiple decouplers, the effect can be magnified and difficult to ameliorate. It could be incorrectly concluded that the pipeline was well protected, however it is known that such off potential values are in error. In some cases, such polarized values do not favour the electrochemical corrosion mechanism and therefore the rate of corrosion is suppressed.

Protective primers can be formulated using lower levels of zinc dust than those defined as “zinc rich”. These products must be carefully formulated - as with zinc rich primers these are typically at a high pigment to binder ratio, using a suitable combination of filler pigments so that the zinc dust particles are not totally encapsulated by the binder and therefore still available to react with the external environment. In the case of these reduced zinc primers, there is insufficient zinc to give true galvanic protection or extensive zinc salt formation and plugging of large corrosion cells, as in extremely corrosive environments such as offshore and marine. These products can provide effective protection in less demanding environments by means of their barrier and pH buffering mechanisms as described above.
are not actually possible on a protected pipeline and instead of having a clean on/off potential waveform it is observed that the OFF potential is supported at a much more negative value.

In the past several tests have been undertaken on well coated pipelines to improve the response during the IR cycle including, capturing the reading later in the cycle, setting the on/off interruption cycle for longer periods or removing the decouplers from the system. These measures were not in all cases successful, and in the latter case, removing the decoupler can result in an unsafe situation as the induced voltage could rise above the 15V ac safe level established by NACE SP-0177 2014.

Given that disconnecting the decouplers in the presence of induced and fault a.c. is a high-risk strategy from a personnel and livestock perspective other methods of providing IR free potential measurements need to be relied upon. Such measurements can be provided by means of coupons using a magnet and a reed switch, to provide potential measurements which can be relied upon to provide an indication of present and ongoing protection. IR free coupons represent a low-cost option for obtaining polarized potentials because they avoid measurement errors due to current flow in the soil and are independent of the pipeline readings and the effects of decoupler capacitor discharge. Coupons may be used for any application where an independent reading is required. In addition, CIPS is not the only method in which pipeline integrity can be established as a DCVG survey may be carried. DCVG is an important and reliable survey method in pipeline construction and in the past has provided an accurate method of locating and recording the severity of line pipe coating defects which expose bare steel. Where indications have been located with DCVG they can be exposed and any damage repaired. DCVG provides a tool which allows the greater majority of coating defects to be located, excavated and repaired thereby limiting the CP current demand and improving pipeline protection. TCO

Readers can submit questions for possible inclusion in this column. Please email the editor on, brianpce@aol.com
TC Energy is a pipeline owning and operating company based in Canada, and has been in business for over 65 years, delivering energy solutions to millions of North Americans. Their natural gas systems operate over 93,000 km of pipeline transporting more than 25% of North America’s supply. In addition, it has nearly 5,000 km of liquid pipeline system providing over 2 billion barrels of oil daily, and it was as part of this liquids system that a major new oil pipeline project was designed to secure an even larger reliable energy infrastructure within Canada and the USA. The project comprised of some 530 km in Canada, while the USA systems added just over 1,400 km of pipeline to connect with the US refining hubs in Illinois, Oklahoma, and the Gulf Coast of Texas. Pipe for the project was originally procured, manufactured and coated in the years 2009, 2010 and 2011. The pipe was then stockpiled in large quantities at several sites throughout Canada and the USA at locations close to the pipeline right-of-way. Once stockpiled, most of the pipe remained un-used until an inspection and remediation programme was started in August 2018.

The majority of the pipe stored in the outer layers of the stockpiles was coated with a whitewash acrylic resin coating to reduce or eliminate the effects of UV degradation. The inner piping at the stockpiles was not protected, as it was determined that the overlying whitewashed coated pipe would eliminate the influence of UV degradation. The only exception being the overhanging pipe ends.

This article describes the short- and medium-term testing programme developed to assess the integrity of the coating on the pipe stored at one site in the USA, and to determine its fitness for purpose as a pipeline coating. The assessment programme was carried out on pipes with the applied UV-resistant paint, as well as evaluating any degradation due to environmental exposure on pipe with little or no UV exposure.

**Effects of Ultraviolet Exposure on Fusion Bond Epoxy Coatings**

When exposed to ultraviolet rays, FBE coatings undergo polymer degradation, commonly referred to as chalking. Previous studies of exposed weathering of FBE coating had identified that this UV exposure could have a serious deleterious effect on the inherent physical properties of the coating (1,2). This phenomenon is common to all FBE coatings that are primarily designed only for below ground service. Kehr (3) stated that, if undisrupted, this layer of chalked FBE will protect the underlaying FBE and enable the coating to retain most of its original properties. However, if this protective layer of chalked coating is removed by rain, wind or intense periods of UV exposure, then the new surface starts to suffer from the repeated process of chalking. As this breakdown and delamination of the outside layers continue, it is accompanied by a noticeable reduction in the coating thickness (2). Work by Cetiner and Kehr concluded that this coating thickness reduction could average between 10 to 40 microns per year. The actual degree and effects of chalking depend upon the following factors:

- Susceptibility of the FBE’s formulation to resist UV breakdown (in other words, not all FBE coatings perform the same when exposed to UV).
The amount of exposure to UV, for example, the 12 o’clock position on a pipe generally suffers more coating breakdown than the less-exposed 3 or 6 o’clock positions.

The intensity and duration of direct exposure to the elements. For instance, UV intensity in areas of the southern USA would be far greater than those in Canada, and hence lead to quicker and more rapid breakdown and chalking of the coating (4).

Availability of water due to rain and morning dew.

Previous studies also demonstrated that when exhibiting chalking and reduced coating thickness, some FBE coatings would exhibit a reduction of their resistance to cathodic disbondment (5). But common to all FBE coatings is their struggle to retain their original flexibility when examined in accordance with the Canadian Standards Association (CSA) Z245.20 cold temperature flexibility test method (6). This aesthetic change of gloss and chalking clearly is accompanied by an embrittlement of the coating, as exhibited by loss of adhesion through the dry adhesion testing (DAT), and reduction of flexibility performance. Any form of reduction in the interaction of UV and the coating via tarping, whitewashing or any other means would therefore be clearly beneficial in reducing or eliminating the UV damage to the polymeric structure of the FBE.

Pipe Data

Specific pipe sections representative of the pipe stocks were subjected to evaluation, namely;

i. 36-in. OD × 0.465-in. WT., API Spec 5L (44th Edition), PSL 2 PSL Grade X70 SAWH pipe coated externally with FBE to the requirements of CSA Z245.20 System 1A4, but noted as without any evidence of the application of an acrylic UV deterioration mitigation system (herein referred to as whitewash).

ii. Same pipe and FBE coating but exhibiting the presence of a post coating applied whitewashed UV deterioration mitigation acrylic paint on all exposed areas, exclusive of the pipe ends.

In total, the whitewashed pipe in the storage facility was estimated to constitute at least 20% of the approximately 24,000 joints of 24m pipe lengths. This pipe had been stored for approximately 18 to 24 months before the application of the acrylic whitewash. That whitewash UV protective coating had been reapplied once after a period of about 4 to 5 years. In all cases, the last few feet at both ends were left bare, so as not to overcoat the stencil and pipe identification markings on each pipe end. However, even after replenishing, the whitewash acrylic resin coating appeared to have significantly faded, as shown in Figure 2. This fading potentially denotes that the effectiveness of this whitewash to resist UV degradation had gradually been reduced during its UV exposure over a 4 to 5 year period.
**Protocol for Assessment**

The objective of this refurbishment assessment was, firstly, to determine the effects that weathering had on the pipe underneath the faded whitewash and to ascertain the quality of that FBE coating. Secondly, to establish a benchmark performance criterion for the coating on pipes that were stored internally in the stockpile and not exposed to UV.

An inspection and test plan (ITP) was prepared to assess the integrity of the pipe coating. The examination consisted of the following:

- FBE coating that had been coated with whitewash acrylic UV protective coating.
- FBE coating from pipes stored in the internal segments of the stockpile that was not exposed to UV (refer to Figure 3).
- FBE coating on the pipe ends or overhanging pipe that was not whitewashed but was exposed to some UV.

The ITP stipulated the following testing activities:

- Documentation of pipe numbers and correlation to location in the stockpile for selected pipe piles.
- Measurement of dry film thickness (DFT) on selected pipe. Frequency and location on pipe to be determined and documented, for example. 12 and 6 o'clock positions.
- Holiday detection inspection on selected pipes.
- Submission of selected pipe for laboratory testing at laboratories in the USA.

**Objective of the Assessment**

1) To enumerate the correlation between DFT and DAT with the integrity assessment evaluations stipulated by the Canadian Standards, and 2) by conducting a series of laboratory testing, establish to the regulators that the dry adhesion and dry thickness testing does quantify the quality of FBE coatings being held at the stockpiles.

3) To confirm the expected conclusion that the non-UV-exposed FBE coating was still fit for purpose as a below ground anti-corrosion coatings.

**Results of the Field Assessment Programme**

Initially, 12 joints of pipe that had been whitewashed and stored on the outside layers of the stock piles were removed. These 12 pipe joints, along with three joints from the interior of the stockpile, were assessed as specified in the ITP defined in the above protocol for assessment.

Figure 4 illustrates the configuration of the whitewashed and non-whitewashed pipe in the stockpiles. All pipes were identified via the stenciling or barcodes.

The results of the DAT and DFT testing are given in Table 1. With a few exceptions, the FBE coating on the piping that was whitewashed still had acceptable coating thickness measurements. The company’s coating specification stipulated a requirement of 406 to 457 microns of FBE coating during manufacture. A range of 404 to 468 microns was recorded on this whitewashed coating, putting it completely in the range originally stipulated for this coating. However, the DAT’s performed on those white washed pipes no longer consistently met the minimum requirements expected of this coating. Table 1 illustrates that eight out of the 10 test joints failed to attain the acceptable DAT ratings of 1 or 2. On the other hand, the pipe that was not whitewashed and was exposed to UV continuously during storage (ie the overhanging exposed pipe ends) exhibited complete failures in DAT evaluations. In addition, this UV-exposed non-whitewashed FBE coating had a remaining coating thickness in the range of 162 to 215 microns. In comparison to the company specified coating thickness, it was apparent that an average coating loss of approximately 25.4 microns per year occurred on UV exposure. This coating deterioration was generally within the accepted industry range of 10 to 40 microns for FBE coating loss per year, when exposed continuously to UV (3).

Initial testing on non-whitewashed coated pipe that had been stored in the interior of the stock piles provided excellent results and showed they were clearly fit for purpose (Table 1).

In addition, two additional non-whitewashed joints from the interior of the stockpiles were more comprehensively examined at the stockpile site, and the results of that assessment are given in Table 2. Basically, each joint was quarantined and tested at three separate locations along each pipe. At each location DAT and DFT testing was completed at the 12, 3, 6 and 9 o’clock positions. All coating on those pipes provided excellent results. The DAT test results were of the highest standard, with each test producing a prefect rating of 1. Also, the average coating thickness was within the range of 450 microns, which was totally comparable with the original factory recorded average thickness readings of 430 microns.

Two test rings from each of these two pipes were then deemed as the focus for further laboratory testing. Each test ring was of sufficient size to allow for specimen preparation to perform the range of applicable tests according to Table 4 of CSA Z 245.20-14 and Clause 7.3.3.3 of the company’s specification TES-CO-FBE-GL Revision 09. One test ring from each pipe was shipped to a 3rd party lab in Texas, USA, and the other test ring from each pipe remained for testing at coating laboratory at the storage site.

**Laboratory Assessment Programme**

The non-whitewashed coated pipe that had not been exposed to the elements, and the whitewash-coated pipe, were assessed according to CSA Z245.20-14 Table 3 criteria for the following properties:

1. 2.5° degree flexibility testing at −30°C
2. 24-hour cathodic disbondment test at 3.5 V and 65°C
3. 24-hour water soak adhesion test at 75°C
4. Additional 1.5° flexibility at −30°C (three specimens, in accordance to Clause 7.3.3.3 of TES-CO-FBE-GL Revision 09), was included to examine and check for any stress, strain or pigment migration markings

The use of differential scanning calorimetry was not considered for this programme due to the deleterious moisture absorption effects on the interpretation of those thermal tests (8).
Results of Laboratory Testing of Whitewashed Piping and Exposed Pipe Ends

The CD results of the non-whitewashed pipe ends exposed to UV were deemed total failures (Figure 5). Whereas the whitewash protected coatings fared much better with cathodic disbondment testing (CDT) results of approximately 5 mm disbondment, and water soak adhesion ratings of 2. However, this whitewash FBE coating demonstrated a serious deterioration in its flexibility performance.

The flexibility tests were all deemed failures on the UV-exposed pipe ends and whitewashed piping. The testing degree per pipe diameter length of pipe was reduced from 2.5 degrees to 2 degrees and then 1.0 degree, however all of which demonstrated similar results of cracking within the coating.

Results of Laboratory Testing of Non-Ultraviolet Exposed Pipe

Overall, the laboratory test results on non-ultraviolet exposed pipe proved to be excellent. The results are given in Tables 3 and 4, and clearly demonstrate the coating that was not exposed to UV or weathering was still totally fit for purpose and retained most of the properties it exhibited at its production.

Observations

All non-whitewashed pipe that was exposed to continuous UV at the storage site, such as pipe ends and stenciled areas, were deemed no longer fit for purpose. Coating loss was approximately 25.4 microns per year.

All coated pipe that was tested from the internal areas of the stockpile, and thus not exposed to weathering, was deemed to be totally fit for purpose by passing all the required CSA tests. The only exceptions were the pipe ends that may have been exposed to UV due to overhang in the stockpile.

All whitewashed coating exhibited good retention of coating thickness and cathodic disbondment and hot water soak adhesion characteristics. However, the flexibility of the underlaying FBE had been adversely affected to the point where the coating was no longer acceptable. This depression of the flexibility levels of the coating could have been caused by the combination of moisture absorption and elevated temperatures. When the faded whitewash coating no longer acted as a reflective mechanism, the surface temperature of the coating increased during the prolonged periods of exposure to intense sunlight. A future study is required to understand if pigment migration, plasticiser effects or changes in mechanical properties due to moisture absorption were the actual root causes of the phenomenon, whereby only the flexibility properties of the coating were affected in such a deleterious fashion.

The whitewashed protective coating was originally applied some 18 to 24 months after the pipe was coated. In the intervening years, there was only one other application of this whitewash coating. From the results gathered in this programme, it can be inferred that if the whitewash coating had been applied on a more regular basis; for example, every two years, this deterioration of the coatings’ flexibility may have been prevented.

Conclusions

The non-protected FBE coatings exposed to UV for periods of up to 9 years completely failed to retain their original properties and attributes. Conversely, coatings that were completely protected from any UV exposure still possessed all their original coating thickness and physical traits.

Even after nearly a decade, the use of whitewash UV protective coatings proved to be extremely successful in preserving and retaining the original DFT thicknesses of the FBE coating. Apart from the elasticity of the coating, UV protective coatings conserved many of the physical characteristics of the underlaying FBE coating. A more frequent application of non-faded whitewash coating to potential UV-exposed coatings, could possibly have also maintained the elastic characteristics of the FBE coating.

References


Figure 5. Cathodic disbondment test results for the non-whitewashed pipe ends exposed to ultraviolet.


Acknowledgements
The authors would like to acknowledge the contribution of Snehal M. Patel, Vice President, Welspun Tubular LLC and P.N. Mahida, Associate VP Quality and Technical Services, at Welspun Tubular LLC Little Rock, to the success of this program.
A thanks also to Casey Bajnok of TC Energy for supplying background details of the project, and to Heather Traub and Kat McTavish of TC Energy for graphic and editorial support.

Tables

Table 1: Dry film and dry adhesion test results September 19-20, 2018 on US stockpile pipes, stockpiled for 9-10 years.

<table>
<thead>
<tr>
<th>Pipe Number</th>
<th>Dry Adhesion Test Rating on Non-Whitewashed Fusion Bond Epoxy Exposed to Ultraviolet</th>
<th>Dry Adhesion Test Rating on Whitewashed Fusion Bond Epoxy Exposed to Ultraviolet</th>
<th>Thickness of Non-Whitewashed Fusion Bond Epoxy (microns)</th>
<th>Thickness of Whitewashed Fusion Bond Epoxy (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1009A26216</td>
<td>5</td>
<td>4</td>
<td>165 - 206</td>
<td>412 - 457</td>
</tr>
<tr>
<td>A1009A22997</td>
<td>5</td>
<td>3</td>
<td>124.5 - 188</td>
<td>416 - 546</td>
</tr>
<tr>
<td>A1009A22998</td>
<td>5</td>
<td>2</td>
<td>157.5 - 200</td>
<td>409 - 526</td>
</tr>
<tr>
<td>A1009A26247</td>
<td>5</td>
<td>2</td>
<td>142 - 162.5</td>
<td>396 - 434</td>
</tr>
<tr>
<td>A1009A25692</td>
<td>5</td>
<td>4</td>
<td>124.5 - 142</td>
<td>396 - 450</td>
</tr>
<tr>
<td>A1009A25343</td>
<td>5</td>
<td>4</td>
<td>190.5 - 208</td>
<td>391 - 429</td>
</tr>
<tr>
<td>A1009A26360</td>
<td>5</td>
<td>4</td>
<td>145 - 231</td>
<td>409 - 444</td>
</tr>
<tr>
<td>A1009A25787</td>
<td>5</td>
<td>4–5</td>
<td>206 - 234</td>
<td>424 - 485</td>
</tr>
<tr>
<td>A1009A26356</td>
<td>5</td>
<td>3</td>
<td>142 - 213</td>
<td>381 - 450</td>
</tr>
<tr>
<td>A1009A26853</td>
<td>5</td>
<td>3</td>
<td>180 - 260</td>
<td>412 - 465</td>
</tr>
<tr>
<td>A1009A41511</td>
<td>5</td>
<td>5</td>
<td>157.5 - 234</td>
<td>290 - 368</td>
</tr>
<tr>
<td>A1009262078</td>
<td>5</td>
<td>5</td>
<td>129 - 292</td>
<td>292 - 348</td>
</tr>
<tr>
<td>A1009A05252</td>
<td>1 (see note 1)</td>
<td>Internal pipe</td>
<td>388 - 452</td>
<td>-</td>
</tr>
<tr>
<td>A1009A05256</td>
<td>1 (see note 1)</td>
<td>Internal pipe</td>
<td>370 - 450</td>
<td>-</td>
</tr>
<tr>
<td>A1009A05238</td>
<td>1 (see note 1)</td>
<td>Internal pipe</td>
<td>404 - 450</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes: 1. Signifies an excellent pass. Specification required a coating thickness of 406 to 457 microns of FBE

Table 2: Dry adhesion testing on non-ultraviolet exposed pipe at US storage site on December 10, 2018.

<table>
<thead>
<tr>
<th>Test Pipe</th>
<th>Dry Adhesion Test No.</th>
<th>Test Temperature (°C)</th>
<th>Dry Adhesion Test Rating</th>
<th>Average Fusion Bond Epoxy Thickness (microns)</th>
<th>Intersect Angles (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34189</td>
<td>1</td>
<td>15.5</td>
<td>1</td>
<td>422</td>
<td>40</td>
</tr>
<tr>
<td>34189</td>
<td>2</td>
<td>11</td>
<td>1</td>
<td>423</td>
<td>40</td>
</tr>
<tr>
<td>34189</td>
<td>3</td>
<td>14.5</td>
<td>1</td>
<td>471</td>
<td>40</td>
</tr>
<tr>
<td>34192</td>
<td>4</td>
<td>19.5</td>
<td>1</td>
<td>476</td>
<td>40</td>
</tr>
<tr>
<td>34192</td>
<td>5</td>
<td>10.5</td>
<td>1</td>
<td>449</td>
<td>40</td>
</tr>
<tr>
<td>34192</td>
<td>6</td>
<td>16.5</td>
<td>1</td>
<td>450</td>
<td>40</td>
</tr>
</tbody>
</table>
### Table 3: Laboratory test results for non-ultraviolet exposed pipe at US storage site on December 11, 2018.

<table>
<thead>
<tr>
<th>Test</th>
<th>Pipe No.</th>
<th>Fusion Bond Epoxy</th>
<th>Results</th>
<th>Canadian Standards Association Z245.20-14</th>
<th>TC Energy Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 water adhesion at 75°C</td>
<td>34189</td>
<td>3M6233-11G</td>
<td>1</td>
<td>1-3</td>
<td>1-3</td>
</tr>
<tr>
<td>24 water adhesion at 75°C</td>
<td>34192</td>
<td>3M6233-11G</td>
<td>1</td>
<td>1-3</td>
<td>1-3</td>
</tr>
<tr>
<td>24 CDT at 65°C</td>
<td>34189</td>
<td>3M6233-11G</td>
<td>3.3 mm</td>
<td>11.5 mm</td>
<td>5.5 mm</td>
</tr>
<tr>
<td>24 CDT at 65°C</td>
<td>34192</td>
<td>3M6233-11G</td>
<td>3.3 mm</td>
<td>11.5 mm</td>
<td>5.5 mm</td>
</tr>
<tr>
<td>24 CDT at 65°C</td>
<td>34189</td>
<td>3M6233-11G</td>
<td>3.8 mm</td>
<td>11.5 mm</td>
<td>5.5 mm</td>
</tr>
<tr>
<td>24 CDT at 65°C</td>
<td>34192</td>
<td>3M6233-11G</td>
<td>3.5 mm</td>
<td>11.5 mm</td>
<td>5.5 mm</td>
</tr>
<tr>
<td>2.86-degree bend at −30°C</td>
<td>34189</td>
<td>3M6233-11G</td>
<td>Two cracks</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>2.86-degree bend at −30°C</td>
<td>34192</td>
<td>3M6233-11G</td>
<td>Pass (no stress marks)</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>2.47-degree bend at −30°C</td>
<td>34189</td>
<td>3M6233-11G</td>
<td>Pass (no stress marks)</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>2.47-degree bend at −30°C</td>
<td>34192</td>
<td>3M6233-11G</td>
<td>Pass (no stress marks)</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>DAT Test at 16°C</td>
<td>34189</td>
<td>3M6233-11G</td>
<td>1</td>
<td>NA</td>
<td>1-2</td>
</tr>
<tr>
<td>DAT Test at 17°C</td>
<td>34192</td>
<td>3M6233-11G</td>
<td>1</td>
<td>NA</td>
<td>1-2</td>
</tr>
</tbody>
</table>

Notes: CDT = cathodic disbondment testing, DAT = dry adhesion testing, mm = millimetres, NA = not applicable, NR = not recorded

### Table 4: Laboratory test results for non-ultraviolet exposed pipes at the 3rd party Laboratories in Texas, January 10, 2019.

<table>
<thead>
<tr>
<th>Test</th>
<th>Pipe No.</th>
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Notes: CDT = cathodic disbondment test, DAT = dry adhesion testing, mm = millimetres, NA = not applicable, NR = not recorded
An overview of energy pipeline integrity management, and future asset management strategies

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Pipelines are one of the most important energy transportation arteries and it is assumed they will continue to be a secure tool for energy transmission for many more decades. Among the different pipeline systems, gas pipelines are most important and vital. Due to the requirements for higher safety and reliability, integrity management has become an important programme to manage risk and develop proper inspection planning. This article gives a review of pipeline integrity management processes used in the industry, and based on this, recommendations for using these are given that will provide a guide for pipeline operators and managers to improve their practices.

Recently, pipeline integrity has seen the introduction of many advanced technologies to detect anomalies, enhance the efficiency of pipeline operation and reduce failures. Pipelines and accessories are valuable assets, generally owned, operated, and maintained by pipeline companies. In most countries around the world pipelines are an irreplaceable core of a gas or other materials transportation system, and a means by which gas or fluids are delivered from the source of supply to the customer.

Gas pipeline integrity management is needed to a gas pipeline is free from incident in its operation, and also to ensure that any anomaly or defect does not have an effect on health, safety, environment, business loss, company reputation, or production and financial loss.

According to DNV-RP-F116, pipeline integrity is the system’s ability to operate safely and withstand the loads imposed on it during its lifecycle. If a system loses this ability, a failure can occur.

Pipeline networks are undeniably superior to other transportation systems, for instance, truck, train, etc., due to their cost effectiveness, security, higher reliability, safety and environmental friendliness over long distances. With all these aspects, pipeline infrastructures represent a high capital investment and due to this, pipelines must be free from the risk that could cause potential threats to life, or harm environment. Pipeline integrity design, monitoring and management become crucial to their operation (see, Figure 1). For example, improper maintenance of natural gas pipelines may cause explosion and fire resulting from pipeline leaks or perhaps rupture (e.g., References 2 and 3).

Figure 1: Pipeline Integrity Management System (reference 1).
Asset integrity management has been described as the continuous assessment process applied throughout the design, construction, installation and operation phases, to assure that the facilities are, and remain to be, fit for purpose. The aim of the asset integrity management process is to provide a framework for the following:

- Compliance with company standards, regulatory and legislative requirements
- Assurance of technical integrity by the application of risk based or risk informed engineering principles and techniques
- Delivery of the required safety, environmental and operational performance
- Retention of the License to Operate
- Optimisation of the activities and the resources required to operate the facilities whilst maintaining system integrity
- Assurance of the facilities’ fitness for purpose

Different energy pipeline asset management systems have been developed. Reference 4, for example, provides a holistic approach for energy pipeline asset management where the asset management system, asset management lifecycle activities and asset management procedures are presented and discussed in detail. It provides a guideline for energy pipeline owners and operators to manage their pipelines for safe operation.

**Pipeline Integrity Threats**

According to ASME B31.8S (Reference 5), there are twenty one threats, nine categories of failure types, and three time-related defect types that could compromise the integrity of a natural gas pipeline. These nine classifications of failure types are:

- Manufacturing defect
- Materials and construction defects
- Stress corrosion cracking
- Internal corrosion
- External corrosion
- Equipment and related defects
- Third-party perpetrated damage
- Incorrect operations, maintenance and procedures
- Weather-related, earth-related and other outside unforeseen forces

The incidents reported can be broken down according to category, for example, gas leaks (40%), fire (14%), un-approved installation (13%), pipe damage, but no rupture (13%), other (20%), and by cause, 3rd party (60%), network integrity failure (20%), non-compliant installation (17%) and operator error (3%).

Gas pipeline metal loss due to corrosion is the biggest threat to pipeline integrity programmes. Corrosion constitutes to the first three threats to liquid and gas pipeline systems highlighted above. It has been reported that about thirty three of the reported cases of hazardous gas transmission incidents are due to corrosion. Common forms of corrosion on transmission gas pipelines are:

- Uniform corrosion,
- Pitting corrosion,
- Cavitation and erosion corrosion,
- Stray current corrosion,
- Microbiologically influenced corrosion.

**Pipeline Integrity Management System (PIMS)**

PIMS are basically programmes describing a company’s approach to pipeline integrity, and driven by the organisation’s engineering functions to ensure the defined integrity goals, objectives and targets are met, while ensuring the safety of public and environment (Reference 6).

**Pipeline integrity requirements**

Pipelines are of an effective means of gas transportation, but if a failure occurs, it can be expensive, involving loss in production, business loss, damage to reputation and environments. Pipeline integrity management is something that can help to optimise the operational costs and control the risk, by providing enhanced pipeline integrity through inspection, testing and analysis.

In the pipeline integrity management process, parameters related to pipeline performance assessment, inspection, defects, and repair and maintenance, are all considered in building a successful PIMS. Different pipeline systems have different requirements and a programme may contain:

- A process for identifying the pipeline segments that could have high consequences if failure occurred
- A baseline assessment plan
- An analysis that integrates all available information about the integrity of the entire pipeline and the consequences of a failure
- Criteria for repair actions to address integrity issues raised by the assessment plan and information analysis
- A continual process of assessment and evaluation to maintain pipeline integrity
- Identification of preventive and mitigation measures for protecting against failure in the areas of high consequence

**Integrity Management Process**

As stated above, gas pipeline integrity management is a process to avoid any failures through activities like inspection and repair, and to assist pipeline operators in enhancing their assets with longer service life and higher reliability. With entire economies built on reliable pipelines, their integrity is receiving more and more attention in management.

Any integrity management process should include the following steps:

1. Identify potential pipeline impact by threat
2. Gathering, reviewing, and integrating data
3. Risk assessment
4. Integrity assessment
5. Responses to integrity assessment, mitigation (repair and prevention), and setting inspection intervals
6. Update, integrate, and review data
7. Re-assess risk

By completing the above steps, a detailed integrity management plan can be developed. Such plans will address prevention, detection, and mitigation practices to avoid failures on pipelines. Improvements in asset management can bring huge benefits by possibly reducing the maintenance cost through proper planning, selecting the right inspection tool, using qualified people, and maintenance and refurbishment of existing infrastructure to extend its economic and safe life. One of the major concerns with the integrity of a pipeline is the risk associated with leakage and explosion which must be kept as low as possible. The importance of asset performance in terms of its capability to transport gas may be less of a management issue than ensuring the integrity of the pipeline.

**Risk-based management of gas pipeline**

Risk is defined as the probability of an event that causes a loss and the potential magnitude of that loss. Risk changes with changes in either the probability of the event, or the magnitude of the potential loss. To perform risk-based management, an analysis of the causes of the risks and an estimation of the failure probabilities need to be carried out, as well as a consequence analysis performed (Reference 7).

A key outcome of the pipeline’s asset management plan is to ensure that pipelines are managed effectively and efficiently in the long term by striking an optimum balance between performance, cost and risk, which is the strategy adopted in the new international asset management standard, ISO 55001. For pipeline integrity management, probabilities typically refer to the probability of pipeline failure due to certain defect growth. The consequences are related to the costs incurred by activities like inspection and maintenance, loss of productivity, rehabilitation and investigation, damage to the environment and community, environmental cleanup, etc.
When considering the threats on pipelines, a number of barriers can be constructed to ensure the threat will not cause an incident in piping system. Most systems have multiple barriers that prevent a threat from causing an incident or failure.

**Pipeline inspection management**

Pipeline inspection is an integral part of pipeline integrity management system. Detailed inspection is the key to safe and reliable pipeline operations. Most common inspection techniques used for pipeline integrity assessment are:

- Pigging,
- Hydro-testing,
- External corrosion direct assessment (ECDA),
- Internal corrosion direct assessment (ICDA),
- Advanced NDT techniques like Air Drones etc.

**Conclusion and Discussion**

Pipeline owners or operators around the world have as their primary objective to transport commodities in a safe and reliable manner. There has been high investment by regulators, operators, and vendors to detect and mitigate any risks and develop robust preventive measures. This article has given a general overview of an energy pipeline integrity assessment/management process. Pipeline integrity can be achieved and managed efficiently through the analysis of different threats or hazards that might cause risks to pipelines.

Based on hazard identification, risk assessment techniques can be applied, and appropriate pipeline integrity monitoring and assessment methods can be conducted both internally and externally. A knowledge structure and process engineering approach are proposed for pipeline integrity management.

**References**

The process of applying coatings to ships, the associated surface preparation and inspection activities (the coating process) for new construction, dry-dock repair and maintenance has hardly changed over the last 50 years. However, regulations in the meantime have resulted in changes to paint formulation, and increased pressure on ship owners and shipyards to consider more environmentally friendly solutions that would reduce waste and impact on health, safety and the environment. Inspection regimes have gradually become stricter resulting in additional work to rectify poor workmanship.

While limited attempts were made in the 1970's [1], to consider how vessels may be painted in the future, little has since been done to look at the future possibilities. Currently, the industry is exploring the concepts of the unmanned ship operation and increased automation in ship building and repair. This two part article aims to highlight the areas where significant changes and technology developments will be required to meet the challenges of building, repairing and operating ships in the future, and to identify technologies that may offer solutions to some of these problems against the background of increased regulatory and environmental concerns.

Introduction

The marine coating market is estimated to consume about 900 million litres of coatings per year, and in total is worth about £20 billion (this includes paint, application and cost of failure (insurance claims and litigation) [2]. This should be compared against the estimated £2 trillion the world spends on combating corrosion in general [3] and the estimated £160 billion it spends on all coating types [4].

Hence, for many of the paint manufacturers participation in the marine market is a relatively small revenue generating activity compared to other sectors such as the decorative and the broader protective coatings sectors. Thus, development of new technologies specifically for marine applications may not always attract the required investment, as both the products and methods of application are generally valued at the commodity level.

Furthermore, many paint companies increasingly focus their investment into related services such as hull performance monitoring, vessel tracking, underwater hull cleaning and other “smart solutions” and initiatives that can be broadly “wrapped around the paint in the can”.

Like any other engineering system on board a vessel, the goal of a coating system is to deliver predictable performance and allow costs to be managed in service. A bulk carrier designed with the required corrosion allowances stipulated in the IACS Common Structural rules would fail to comply with classification rules after 5 years in service were it not coated with suitable anti-corrosion paint [5], also the Safety of Life at Sea Convention (1974 as amended) (SOLAS) mandates the need for ballast tank and crude oil tank coatings through the Performance Standards for Protective Coatings, PSPC [6,7]. In addition, classification societies provide verification and type approval services for a range of coating types and activities (e.g.shop primer, anti-corrosives, anti-fouling, crude oil tanks and ballast tanks), however this focus is mainly on the coating process once new construction starts.

The importance of design is referenced in the PSPC, ISO12944, and the Marine Paint Forum Guide amongst other standards and industry guidelines. Although the existence of these standards and industry guidelines has resulted in few significant changes in methods and practices, and in certain aspects such instruments may have inadvertently hindered innovation [6].

At new construction, coating work is the production bottleneck that limits shipyard capacity and results in the highest levels of re-work, while the chemical, cargo and ballast tank, and anti-fouling coatings regularly cause problems in operation:

The cost of the paint is typically less than 0.5% - 2% of the new build cost of the ship and less than 1% of the annual operating budget, with a peak at dry-docking when the anti-fouling is renewed.

The coating process is still relatively labour intensive although attempts to automate work and access have been made; see Figure 1. According to the authors own analysis, coating work can account for somewhere between 10-15% of the total cost of building a ship.

Figure 1: Example of semi-automation in surface preparation.
In addition, tank refurbishment (ballast or cargo tanks/holds) can incur significant cost penalties in terms of off-hire costs, and while some owners use the option of riding squads for some of this work, the cost of access and H&S issues make this a difficult process whether the ship is underway or alongside. At new building, and in dock, the costs can include considerable amounts of repair and touch up of the newly applied coating that has been damaged because of poor scheduling (this can account for up to 30% of total coating man-hours at new construction [8]).

The increased concern over Health and Safety will also need to see a step change in how coatings are inspected, and while the IMO has issued guidance on Permanent Means of Access [9], there have been considerable concerns from major operators, class societies and insurers, regarding loss of life in enclosed spaces, in particular because of the inspection requirements [10].

During ship repair it is estimated that almost 75% of the waste stream generated from a dry-docking is from the coating process and associated use of consumables and coatings [9]. There is a clear need for improved methods of surface preparation and application to reduce the environmental impact of the coating process.

This article reviews the coating process and identifies the areas where change is needed, and where possible identifies technologies that show promise (possibly near to market, or being used in other markets), or suggests where research and development should be carried out.

It will be published in two parts, and this first part will concentrate on the influence various parties have on the coating process and how the design phase affects this.

The current viewpoint

In any gathering of paint experts one of the regular laments is that coatings fail because of poor surface preparation and poor application. However, data from the authors’ work over 20 years has indicated that this is not necessarily the case, and that while these may be symptoms of failure, they are not in most cases the root cause of the failure. This conclusion does counter the long-held industry belief that it is poor surface preparation and application that are the cause of coating failure, however given the required inspection regimes, then if this long-held belief is true, the implication is that certified coating inspectors are not able to carry out their task properly.

An analysis of the failures investigated by the authors is summarised by root cause in Figure 2 which shows how important factors such as design, specification and product selection, could affect a coating’s performance. While the authors accept that there may be considerable variability in the experience of coating inspectors/technical service personnel, factors which determine a coating’s performance are decided well before any coating inspection takes place. The determination of the suitability of a surface preparation for coating, is usually based on visual standards e.g. surface cleanliness, which can make an objective determination very difficult. This raises a cause for concern and a need for a change in approach.

Also, decisions made on site can result in a change to surface preparation and/or application methods which can result in premature coating failure, e.g. “cosmetic coats” to cover up repairs without considering the impact on the intended performance, or paint company recommendations. Changes in surface preparation method/quality due to lack of available equipment or skills, result in poor in service performance.

For new building work, it is clearly in the interest of the shipyard to “get it right first time” as this minimises the overall cost and time of a project. In dry-dock, contractors are usually rewarded based on man-hours and so potentially the incentive to improve the process is lower, with time and competitor pressures tending to drive quality down to ensure profitability. On-board maintenance by the crew has huge variability in terms of quality and quantity of work carried out, however it is a relatively low proportion of the overall operating budget and this tends to relegate it well down the list of operational priorities for most of ship owners.

Standards are readily referred to within specifications or on technical data sheets but without understanding the implications for specific tasks [11]. It is a common misconception that all standards were written with ships in mind rather than for a broad range of coating activities covering a range of structures (from buildings to rail cars). Therefore, standards must be subject to scrutiny and discussion before any project starts to agree how they should, and will be, applied. It is more common that standards are only considered once a problem arises and a dispute is well underway, only to then be interpreted differently by the parties involved. There is an urgent need to make these standards more relevant to the shipping industry and improve the technical integrity of some (e.g. IMO PSPC).

The decision-making process of the various parties

The ship owner

There are different kinds of owners, and ownership patterns, which can impact coating selection, expenditure, and ultimately performance, irrespective of the quality of the work at new build or during repair, or the level of experience of the inspectors. Owners can be broadly divided into four categories, private, public, state, and financial [12].

The period of ownership of individual vessels differs on average by company type, for example financial companies (banks, funds, etc) tend to keep assets for significantly shorter periods of time, whereas state owned companies tend to hold on to them for much longer. Also different companies have different investment horizons, and the time frames to realise the return on their investment could be significantly different, and hence the willingness to invest in the longevity of the vessel can also vary considerably.

Vessels can have as many as 5 to 8 owners over their lifetimes depending on type. Bulk carriers tend to have more owners on average than both tankers and container vessels. It was also found that the first owner tends to keep the asset the longest which usually covers the first and second special surveys [12]. However, ships’ economic lives are finite, and on average this is about 25 years. When strict regulations are enforced that require costly retrofits, many owners tend to scrap older tonnage, so the average economic life of vessels shortens. For vessels with multiple owners, this results in frequent changes of ownership and very short periods of ownership. For shipowners whose main priority is to generate profit based on the market fluctuations, and who tend to buy and sell vessels speculatively, there is little incentive to spend on the coating process and general maintenance.

All these factors make the management of coatings problematic, as every change of owner can result in a change in coating specification and coating company, making the coating process unique among the various engineering systems on board the ship, which otherwise generally last the life of the ship, or rarely see a change in supplier.
In terms of vessel integrity, the Classification Societies have a key role as they are often the recognised authority to assess coatings in ballast and crude oil cargo tanks.

Ship owners also change Classification Societies for a variety of reasons, for example, usually when a ship is sold. The change of ownership and Classification Society can lead to a lack of continuity in terms of an intimate knowledge of how the coatings perform in service, and similarly when a change of paint supplier occurs this also limits the extent to which any lessons learned about performance can be put into practice. This has generally limited attempts to draw meaningful data about coating performance across from different manufacturers and coating types.

The Equipment supplier

The marine market for surface preparation and coating application equipment is limited, and small compared to the needs of other manufacturing industries, such as the car industry, which has many more customers and therefore can generate greater sales than the marine market. Consequently, development of surface preparation and application technology tends to dominate in these markets where mass production readily justifies investment in automation.

The coating process technology used in the shipping industry is very mature and is at the phase where every possible benefit is being squeezed out of the existing technology to keep pace.

The coating contractor/manager

Because of the mature level of technology used in coating application, there are very low barriers to entry for a new company, and this has led to the existence of numerous small coating contractor companies that are often used by ship yards and by ship repair companies as a way of balancing the labour demand during the build or repair process. The market is therefore competitive, for example more than 40 coating contractor companies are present in Singapore alone. There are a few companies that have tried to establish themselves as international players, but they then generally suffer from a cost disadvantage, and the market does not offer much scope for them to increase prices to reflect the “superior” service or technology they may be able to provide.

Drawing a comparison between the welding process and the coating process can highlight one of the major problems. Welding work is usually carried out under the supervision of a welding engineer, which generally implies that the “Engineer” is university educated at least to a bachelor’s degree level. The coating department however is often under the supervision of a coating “Manager”, who in most cases does not have a university education but has usually risen through the ranks based on experience and craft skills. The more likely qualification held will be that of a coating inspector e.g. FROSIO, ICorr, NACE or equivalent. In many of the leading shipyards there are a growing number of qualified chemists/corrosion engineers who either undertake this role or support the Manager.

Also, the typical welder will have undertaken training and certification testing which must be regularly renewed and reviewed, while for surface preparation and coating work, the type of training available is generally of a lower grade and traditionally the requirements are informal. In most cases for coating work there is training but no certification, and turnover of personnel in the coating process tends to be high, however this is slowly changing in some industry sectors with such as ICATS from the Institute of Corrosion.

This simple comparison serves to indicate the challenges that the coating process must overcome to increase productivity and provide cost savings through life of the vessel.

The shipyard

In the same way that there are different types of owners there are also different types of shipyards, those that are high volume producers of a range of vessels (e.g. S.Korea) and those that are specialist builders of fewer vessels e.g. cruise ship or naval ship builders. Some build in the open air and some build in enclosed facilities. The production needs of these yards varies in terms of speed of build and throughout which are important factors in coating selection e.g. drying times, over-coating intervals, and key features of shop primers such weathering, cutting and welding.

Coating product development is often driven by the needs of the major shipbuilders e.g. China, Japan and South Korea, where most of the marine coatings are sold, and hence these markets become key targets for the coating company product development programmes. This tends to result in performance solutions for these major facilities, requiring that the many smaller facilities or specialists’ builders have to adapt products to their specific needs.

Local regulations and environmental concerns are increasingly playing a key role in this area e.g. the use of abrasive blasting in some shipyards can be restricted, or the need to limit Volatile Organic Compound Emissions (VOCs) can adversely affect the production performance of a facility.

The current challenges and possible solutions for the coating process in future.

The present-day imbalance

One of the key problems is the lack of coordination between the new build and in-service requirements. At new build, the team is mainly focused on the delivery of the vessel on time and on budget, and in many cases show little thought or concern about the in-service operational costs/needs.

In terms of the paint supplier, the ability to follow a vessel throughout its life is hampered by the varying patterns of ownership, often resulting in new owners switching paint supplier, and in short-term interests, that tend to lead to lower cost, rather than best practice.

The shipyard’s interest in a vessel is only over the 12 month warranty period. The paint company has the shipyard as the client initially, and then the owner, who may only keep the vessel with the same paint company until the next dry-dock. Thus, there is often little consideration of through-life performance and how best to measure it.

It is often said today that the major new build yards wield too much influence, and the price pressure on owners to accept standard designs can often result in an increase in through-life operating costs. Until this is resolved by proper feedback mechanisms, then new build designs and selected coating schemes will always compromise future operating costs.

The situation is being compounded by the fact that few ship owners employ coating experts directly, and who are often recruited to be part of the site team for a new build, while in the technical departments at head office or in the management companies, there are very few companies that can claim to have genuine in-house expertise with respect to corrosion and coating.

Vessels being managed suffer even more because of the competitive nature of the industry and natural owner resistance to pay for “enhanced” services when they are considered to be the responsibility of the ship manager. As an extreme example, a ship management company could be dis-incentivised from adopting novel solutions that could save the client money but increase their own costs, which they may not be able to recoup.

This implies that there is a need in the market for a “Total Coating Management” service, which can consider the through life engineering requirements of the coating system, tied to the ship itself rather than the owner, and provide each owner with round-the-clock support for the coating needs including longer term behaviour analysis, and provide the specialist support to owners/ managers/charterers and others.

Process variability

One of the key challenges facing the coating process is that of variability or predictability. When coating a complex space such as a ballast tank using the IMO PSPC regulation and good practice guides as provided by many paint companies, a manual surface preparation process is required to provide a Sa2.5 cleanliness finish. The profile of this finish is in the range 30 – 75 microns, whereas the coating to be applied is in the range of 280 to 640 microns, typically two coats of paint in areas of complex geometry. Thus, the manual application process must deliver a tolerance of 360 microns (the difference between the minimum and maximum thicknesses).

Variability of the application process has been assessed [13] and current processes are not capable of meeting these tight tolerances, resulting in elevated paint thickness and/or inadequately prepared surfaces.

Design Problems

The way in which ships are designed, including their structural configuration, has been optimised over many years to ensure efficiency and consider
key parameters such as cargo carrying capacity and speed. Very little consideration has been given to the concept of design for coating, and rarely (if ever) have the authors seen reference to ISO 12944-3 in any paint specification with its emphasis of design for coating detailed features like scallops and welding configurations.

Standard access holes in tanks are generally too small for workers to easily access with the required equipment and lighting, and make the process of ventilation and curing much harder. Work with a Dutch yard [5] showed that where additional effort is made then designs can be modified to reduce the number of edges (a regular source of coating breakdown and corrosion), improve access with bigger holes, and reduce total surface area for coating that could lead to considerable cost savings for the shipyard.

Yet it is still common today to see designs that, while they may provide productivity savings in steel work or weight, create significant problems in service by using dissimilar metals, complex geometrical design, or provide tight spaces which make it impossible to properly prepare and coat with the technology that is available today.

Design today has its limitations; classification rules require key structural inspections to be carried out at arm’s length and hence result in considerable expense in the provision of temporary means of access.

Many of the issues that arise are repeated across a range of designs because CAD systems have over the years developed a library of standard parts/pieces that are simply used from one design to another. However, the blame cannot rest with the designers as there is no reason to change anything if there is no feedback from in-service performance. While shipyards do carry out a 12-month end of warranty survey there is often no real direct route for feedback and even major owners are rarely able to impact on the shipyard design process, which is optimised for steel production rather than coating and in-service performance.

**Future Design Solutions**

The use of mild steel will likely prevail for the immediate future, but the potential use of ‘Graphene’ to allow different structural configurations to replace the stiffened flat panel, as has been often envisaged with corrugated core laser welded panels, could be realised [14]. Such a change would allow increased structural efficiency and offer different options for corrosion protection and smooth flat surfaces for functional coatings to be applied.

Design improvements can be also made by upgrades to standards such as ISO 12944-3 to address specific issues related to marine structures. Furthermore, such standards should be referenced in design and coating specifications.

Access for work and inspection is critical to the through-life performance of the coatings and the operating cost of the vessel. The considerable amount of effort being placed in the development of Drone technology to carry out surveys, which the authors believe will have a considerable impact on vessel design in the future. In addition, technologies for underwater hull cleaning/surveying and paint removal will also evolve and need designs to be developed to take their requirements into account.

Other key areas are naturally cargo tanks and holds and chemical cargo tanks. For cargo holds issues of abrasion and cargo handling damage need to be investigated and new design configurations considered. Attempts to use stainless steel for chemical cargo tanks have found some success but this in turn raises the issue of dissimilar metals being used in the ballast tanks, and in addition, stainless steel is not without its maintenance needs in the form of re-passivation.

Any design should thus aim to minimise the coating challenge over the life of the vessel, with the desired outcome a coating friendly design, which can be defined as one that is not only well suited to enhance the productivity of the new build yard by having simpler structural configuration that minimises complexity and hence access and ease of coating, but also is both optimised for the operational requirements and the likely adopted maintenance regime, and provide asset integrity through-life.

One of the most significant issues for coatings over the last 30 years in terms of structural design of vessels has been the rise in the number of designs that are provided directly by a shipyard which tend to focus on optimising production time and efficiency during the build cycle, rather than the through-life needs of the asset/owner.

**Material selection today**

Once the design of the vessel has been finalised, the single most important factor to longevity is material selection. Steel is the dominant material for the hull structure and at present much hope is being placed on the use of unconventional materials. Stainless steel is not uncommon (in chemical tankers) and even titanium has been considered by the US Navy. It is still not uncommon today to see vessels mixing a range of metals in one space or on one assembly against best practice (see Figure 3).

**Material selection in the future**

Graphene is increasingly referred to as the wonder material of the future, however it should be noted that while the term corrosion is most often related to steel, many other materials corrode or degrade over time by processes other than corrosion (UV exposure for example in the case of rubber).

However, while researchers are looking into the possible applications, [Ref 15], we are still quite away from realising this dream. In fact, while the strength of pure Graphene is substantial, when it is incorporated into resins to make it useful as a material, its strength properties are dramatically reduced, making it unlikely to be a source of an alternative material suitable for large construction projects.

In the meantime, developments in corrosion resistant steel continue [16]. This technology has also been used in the bottom plate of crude oil tank and underdeck areas, and a 50% reduction in corrosion loss has been reported. All these developments could ultimately influence the required performance from coatings.

The potential for new processes and materials also offers promise of a step change in the use of materials for building ships. A key process could be additive manufacturing and and materials such as Graphene could indeed become a key material of the future. Although at present potential use and its application is very limited, but the pace of technology development is believed to be increasing.

**Coating strategy**

Every world class shipyard has a well-defined build strategy that is often very detailed for steel and outfit work but can be lacking in how the coating activity can best be integrated into it. The lack of application of any coating strategy is often reflected by the relatively high levels of re-work that are required in coating activities because of poor integration of the coating process with other activities.

A key issue has been the increased levels of productivity in shipbuilding in general against a set of technologies (surface preparation and coating application) that have not progressed in terms of productivity, and struggle to provide consistent/predictable performance in terms of surface cleanliness and application (a fully automated shop primer line being a general exception to this rule).
Current coating strategy

The building strategy of today generally affords little space for the coating activities despite them often being a bottleneck process [17]. Many shipyard designs and developments often create imbalanced processes by underestimating the needs of the coating process either in the form of too few workshops, insufficient transport capability or (as in most shipyards), the subsequent need to repair the freshly applied coating. If coating technology does not change then more effort has to be put into developing coating strategies that accept the limitations of current technologies.

Coating strategy in the future

If technology does not change then coating strategies will have to be better integrated into the production process and even simple things such as allowing more cycle time for coating work in winter compared to summer will be required. However, technology opportunities continue to emerge in the form of coatings that are more resistant to hot work damage, or hot work technology that is more forgiving to existing coating systems. Low heat input technologies for cutting and welding such as using high-power lasers could provide such solutions, while current technology limits the “self-healing” capability of high build coatings often used on ships.

The next part of this article will cover in detail the coating specifications and standards used today, and what will be necessary in the future. It will also consider the needs of coating technologies in the future.

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BRANCH DATES

10th March 2020
London Branch
1800-2100
Venue: Lancaster Hall Hotel, 35 Craven Terrace, London, W2 3EL
Branch AGM, and the Chairman’s talk.
Bee Technical - a light hearted insight into the realm of keeping Honey Bees, by Paul Barnes

31st March 2020
Aberdeen Branch
1800-2100
Industrial visit
Venue: Oceaneering, Aberdeen AB21 0BR

2nd April
London Branch
1800-2100
Venue: Lancaster Hall Hotel, 35 Craven Terrace, London W2 3EL
Speaker and title to be confirmed

ADDITIONAL DIARY DATES

2nd March 2020
Painting Inspector course – Level 1
IMechE Argyll Ruane, Sheffield

6th March 2020
Cathodic Protection Buried – Level 3
IMechE Argyll Ruane, Sheffield

16th March 2020
Insulation and Fireproofing Inspector course
IMechE Argyll Ruane, Sheffield

18th March 2020
Cathodic Protection Buried – Level 3
IMechE Argyll Ruane, Sheffield

30th March 2020
Paint Inspector course - Level 1
IMechE Argyll Ruane, Sheffield

10th April 2020
Paint Inspector course - Level 3
IMechE Argyll Ruane, Sheffield

20th April 2020
Cathodic Protection Buried – Level 1
IMechE Argyll Ruane, Sheffield

23rd March 2020
Cathodic Protection Buried – Level 1
IMechE Argyll Ruane, Sheffield

30th March 2020
Paint Inspector course - Level 1
IMechE Argyll Ruane, Sheffield

3rd April 2020
Paint Inspector course - Level 3
IMechE Argyll Ruane, Sheffield

16th March 2020
Cathodic Protection Buried – Level 3
IMechE Argyll Ruane, Sheffield

20th April 2020
Cathodic Protection Buried – Level 1
IMechE Argyll Ruane, Sheffield

19th-20th May 2020
Oilfield Corrosion Science and Engineering course, University of Leeds

8th-12th June 2020
Fundamentals of Corrosion for Engineers course, Northampton

17th-18th June 2020
ICorr Coating Inspector Level3, Workshop & Assessment, Corrodere, Newcastle

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