Corrosion Management

Issue 149 May/June 2019

Protecting Reinforced Concrete Structures

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Welcome to the latest edition of Corrosion Management. I have had a lot of positive feedback on the magazine from members recently, particularly regarding the quality of the technical articles, so congratulations to our Editor Brian Goldie on the improvements he has been making. He assures me there is more to come!

This is an exciting time for the Institute, with the recent move to the new Corrosion House at 5 St Peters Gardens in Northampton. Our dedicated office team of Denise, Gwynneth and Sue are now safely installed in the building and the final touches are being made to the furnishings under the watchful eye of Trevor Osborne. On the evening of Thursday 6th June we held a Grand Opening event to celebrate the move to our new home, and all members were warmly invited to attend.

I'm also delighted to announce that Bill Hedges has agreed to take up the vacant position of Vice President of the Institute, subject to a formal vote at the next Council meeting. Bill has been prominent in London Branch activities for many years now, most notably in the development of the Young Engineers Programme, and he brings a wealth of experience and insight from his role as Chief Engineer - Materials at BP. I'm excited about the contribution he can make, and the higher profile he will be able to bring to the Institute during his Presidency.

We have a number of important initiatives coming to the boil at the moment, including a new agreement for provision of ICorr training courses worldwide, a complete overhaul of the Institute brand, a position paper on recruitment and retention of student members, and a proposal for a discounted subscription scheme for retired members. You will be hearing more details about these over the coming months.

In other news, I would like to congratulate one of our members, Liane Smith, who has recently been elected an Honorary Fellow of the European Federation of Corrosion (EFC). This is a significant honour and recognises her impressive contribution to the establishment and continued success of EFC Working Party 13 – Corrosion in Oil & Gas Production. Liane will receive her award at the next EuroCorr conference, which will be held in Seville in September.

Finally, I was privileged to be invited to present the President's talk at the London branch meeting at Imperial College in March. I chose to discuss the future of the Institute and how we might formulate a longer term strategy to adapt to external drivers, such as the transition to low carbon energy, the digital revolution, the growing generational gap and the UK Industrial Strategy. I was very encouraged by the level of audience engagement throughout the discussion and picked up a lot of great ideas from the members who were there. I plan to repeat the process at the other five branches over the rest of the year and would encourage you all to attend your local branch if you can. Your input is very important to the future of the Institute!

ICorr President,
Gareth Hinds.
Welcome to another issue of Corrosion Management, which includes articles on the prevention of concrete degradation, and subsequent rebar corrosion, and planning for cathodic protection surveys. There is also a report from the winning YEP team about what they learned from the presentations during their visit to the NACE Congress in Nashville.

As the President hinted in his column, I am intending to introduce new columns, to further benefit readers. The first will be a technical Question & Answer page, where experts will respond to readers’ questions on topics related to corrosion. The questions should be generic in nature and must not be about specific projects or structures, or proprietary products.

Readers can send their questions for consideration to me at, brianpce@aol.com

Remember, you can also send possible articles for inclusion, case studies, and information about new products or your company, to the same address.

Brian Goldie, Consulting Editor

From the Editor

ICATS News

We are pleased to announce the updated ICATS website has been launched. The address remains the same, http://www.icats-training.org/, but it is more user friendly and works much better with phones and tablets.

As you will be aware ICorr has moved to new offices at Corrosion House, 5 St Peters Gardens, Marefair, Northampton, NN1 1SX. This new facility includes state of the art training facilities where most of our courses will now be presented.

As previously announced, ICATS has also introducing the new ICATS Managers/Engineers Industrial Coating Awareness course. This is a structured training module for managers, engineers, specifiers, and anyone that would benefit from an understanding of coating application. The module covers:

- Health and Safety in industrial painting
- Preparation standards
- Blasting and abrasives
- Mechanical and manual preparation
- Other surface preparation methods
- Painting specification
- Toolbox talks
- Paint technology
- Galvanic series
- Convertible and non-convertible Coatings
- Over-painting existing paint systems
- Paint manufacturers
- Paint failures
- QC and QA

The Industrial Coating Applicator (ICA) faces many issues within industrial coatings, and it is recognised that this role can be misunderstood, leading to a potentially dangerous situation, or misinterpretation, and an expectation of what can or can't be achieved.

These are one-day classroom-based presentations, and the first one is planned for 4th July in Northampton.

The next Supervisor course will be on 2nd and 3rd July, and will also be held in Northampton. Please contact the office, correx@icorr.org, phone 01604 438222, or check the ICATS website http://www.icats-training.org/ for dates and details of all courses.

Launch of new Passive Fire Protection Course

ICorr/IMechE has entered into an agreement with PFPNet, the industry body for Hydrocarbon Fire Protection, with a member base of owners/operators, major applicators, and the engineering community, to develop a PFP training course, the contents of which will be developed by PFPNet, working with ICorr, and will be delivered by IMechE, with the first module is planned to be delivered by the end of this year.

This first course is intended for owners’ inspectors, who are required to inspect PFP coatings, but in addition, other courses are planned, which will include module planned to be delivered for other types of PFP systems, as well as other disciplines within the PFP industry, for example, modules that will supplement professional engineering qualifications, and improve understanding about how PFP should be engineered, specified and installed.

Training will be provided by qualified individuals, and an important part of the overall programme is accreditation of the course, along with qualification of the individuals who successfully complete the training.

A PFPNet conference is planned to be held in Manchester on 5th and 6th June, and there will be a presentation about this new course from IMechE.
ICR have specialised tooling and trained engineers, who deal with the insertion and retrieval of corrosion monitoring coupons in live pipeline valve stations (Online Retrievals). Pre-installed fittings on the pipes allow threaded plugs which carry the mounted coupons to be inserted into the pipe. This is carried out using either mechanical or hydraulic, telescopic portable tooling which can introduce, through the valve gate, fresh coupons of prepared carbon steel which then sit within the line for the study period. Recovery of the coupons allows for weight loss assessment and corrosion pattern studies, which can be used to evaluate the corrosive nature of the fluid and help to provide remedial measures, such as chemical injection solutions.

ICR also offers on-site weldless, flange to pipe connections which are carried out using a hydraulic colletted + ram system. The flanges to be fitted to the pipe have an annular groove which is soaked in epoxy and then systematically wrapped around surface-prepared pipes, T-junctions elbows or structural beam sections, to cover and reinforce damaged or thinned areas of pipe or steelwork. The wrapping fibre used contains a split collet which expands inside the pipe and forces a ring of the pipe wall into the flange groove. This provides a weldless metal to metal gas tight seal which is dressed each end with sealant to prevent water ingress to the junction. This can be performed on pipe to flange connections in any remote situation with 3” to 15” pipes.

A full demonstration of the operation was performed on 10” pipe using the hydraulic compressor and ram, and sectioned flanges were offered to the audience as proof of the integrity and bond.

Finally, a presentation was made on engineering repair solutions for pipe work and structural beam strengthening. These composite repairs use glass and carbon fibre cloth which is soaked in epoxy and then systematically wrapped around surface-prepared pipes, T-junctions elbows or structural beam sections, to cover and reinforce damaged or thinned areas of pipe or steelwork. The wrapping fibre used has a woven nature and anisotropic strength. Once wrapped, a compression bandage is added and within 24 hrs, the epoxy laden fibre will reach its full cured strength. The wrap system is ideal for situations where emergency or temporary repairs are required, but is often suitable for longer term fix until major maintenance programmes are permissible. ICR are also able to wrap pipes under service and low pressure which are leaking. A flanged threaded plate is fitted into the leak and a hose added to divert the leaking fluid while the pipe and edge of the plate are wrapped in the composite. Once the wrap has cured, the threaded plate can be fitted with a blanking plug to reseal the pipe.

At the close of the industrial visit, the Chairman, Dr Yunnan Gao, presented ICR with a certificate of appreciation. Further industrial visits are planned for September 2019 (NCIMB Microbial Laboratories) and March 2020 (Oceanengineer NDT).

The April event was the annual joint meeting with the MCF (Marine Corrosion Forum) where the branch were very pleased to welcome Scaled Solutions Ltd of Edinburgh, to talk on their recent R&D findings into the performance and optimization of corrosion inhibitors, including those for demanding HP (12,000 psi) / HT (300 °C) operations. (The Scottish Government recently recognised Scaled Solutions’ contribution to Research and Development through the provision of a £2.2M grant award in June 2017, to support R&D in several key areas for the Oil and Gas Production industry. This award, together with significant further investment by Scaled Solutions themselves of £3M, should bring significant cost-saving and corrosion prevention benefits to O&G operations).

 Attendees are welcome to join any of the parallel sessions that will be running during the meeting.
It is well known that during qualification of a corrosion inhibitor, it is extremely important to carry out laboratory-based assessments that are prudently representative. However, in practice, there are many variables that can contribute to the corrosive nature of a system and it is often costly and time consuming to accurately reproduce all the different field conditions. Because of this, investigations are normally carried out using an iterative screening programme, starting with simple tests, followed by product deselection and then further more complex tests. The simplified screening tests then determine the preferred products and dose rates which can pass to the next stage of testing. It is therefore vital that these initial screening tests are carried out in an appropriate a manner as possible.

Hunter Thomson explained how Scaled Solutions’ ongoing research into seemingly small changes to test methodologies and conditions in these preliminary screening tests, can significantly influence the outcome of screening studies. A range of corrosion inhibitors based on common chemistries have been formulated by them to test these effects more precisely, and their extensive results to date have illustrated the controlling effect of aspects such as pre-corrosion, the impact of the brine chemistry, inhibitor composition, as well as the effectiveness of partitioning for different chemicals, on the performance and relative performance of different products.

Hunter highlighted how relatively small changes in the methodology adopted, can lead to considerable differences in the observed performance, ranking, and outcome of the pre-screening of corrosion inhibitor chemicals, and that thorough understanding and careful design of corrosion inhibitor screening programmes are essential to eliminating possible errors and test artefacts.

This most interesting presentation generated many questions and proposals for future work, covering topics such as effects of intermittent chemical injection, surface area and scaling.

At the close of the meeting, the chair presented Hunter Thomson with a certificate of appreciation.

Looking further ahead, the branch will be hosting its annual full-day Corrosion Awareness course on 27th August 2019, (via key sponsor Rosco), comprising of a number of lectures/presentations focusing on microbiologically influenced corrosion (MIC) in pipeline systems. This year’s programme will include talks by ROSEN specialists and other visiting speakers, on their MIC Experiences from global operations covering, sampling, analysis, monitoring of pipelines for MIC damage, chemical mitigation / cleaning strategies, and finally inspection, modelling and monitoring approaches.

Most certainly this event will provide a very comprehensive introduction to this very significant and often troublesome area of Corrosion Control/Prevention, and the provisional programme can be found on the Institute website.

Full details of future ICorr Aberdeen events can be found on the diary page of the magazine and on the website, or by contacting: ICorrABZ@gmail.com, and all past branch presentations can also be found on: https://sites.google.com/site/icorrabz/resource-center

The branch AGM was held in March, which was followed by the “President’s talk”. The chairman, Paul Brook, reviewed the activities of the branch over the past year and noted that we had had excellent presentations. The Treasurer, Jim Glynn, announced that again our finances were in good shape, and that surplus monies will be returned to head office. Paul then asked if any members wanted to join the committee, and confirmed that existing members were happy to serve for another year. Paul also informed the meeting that the branch is close to completing a venue move from Imperial College, Kensington to the IMechE offices in Bird Cage Walk, Westminster. This should be a great home for London branch future technical talks, which will restart following the summer recess in October, on the second Thursday of the month as usual. More details will be available on Institute web site in due course.

Gareth Hinds then presented his views on the future of the Institute, and discussed ways we could adapt to changes, including environmental challenges, the rise of digital communications, and how to encourage more young engineers to join the Institute, and how to support them. This generated a lot of discussion and interesting suggestions.

The April meeting, the last of this season, was joint with The Welding Institute, and was given by Alan Denney of TWI, on the subject of “High tensile steel bolts and nuts: hydrogen embbrittlement and failure in corrosive environments.”

Alan started by talking about the failure of threaded components used as shear connectors for earthquake resistance on the San Francisco Oakland Bay Bridge, which has been well documented in the technical press in the USA. These galvanised rods (in ASTM A354 grade BD steel) were pre-installed in 2008 in the supporting piers to the bridge superstructure which are above the water level. The superstructure was assembled and in 2013 the rod connectors were pre-tensioned hydraulically to 70% of UTS. A number of these suffered brittle failure, the published cause of which was that the rods failed due to hydrogen embbrittlement arising from stress corrosion cracking.

Alan then proceeded to explain the conditions required for stress corrosion cracking, namely a combination of a susceptible...
Failures of structural bolts have a long history. Alan mentioned that his first encounter with bolts failing from hydrogen embrittlement was in the 1970s on a television transmission tower, with failures occurring in V grade and Y grade bolts on cold nights; the bolts being found on the ground in the morning, and his most recent experience of a failure was a few weeks before this talk. Apart from in transmission towers, such failures have also occurred in the recent past on prestigious building structures, and in offshore wind turbine towers. Recent occurrences known to Alan have been in large diameter high tensile bolts, generally in bolt grades 10.9 and above. He explained that there was a relationship with hardness of the fasteners (both bolt and nut), and covered recommendations in standards such as those published by DNV-GL for offshore wind turbine structures, which limit the highest strength grade to 10.9. He discussed the typical crack morphologies associated with hydrogen embrittlement and how the fracture surface could be ‘read’.

Alan then discussed some of the metallurgical aspects in bolt and nut materials and the recommendations and findings of work carried out by the Deutscher Schrauberverband (DSV) in relation to the desirable elements in the composition, and their proposed limits on chemical composition. He presented some findings from DSV on the failure thresholds in 10.9 bolts under ASTM F1624 test conditions with different coating types and then finished by summarising the findings:

- There is a risk of stress corrosion cracking with the use of fasteners with a UTS > 1000 N/mm² in a corrosive or marine environment.
- The much-quoted guideline of 380 Hv as the threshold for stress corrosion cracking is not conservative, notably when there is a risk of external corrosion, even during temporary conditions.
- Controls which will improve their performance in marginal situations can be put in place for the bolt materials, their heat treatment and metallurgical controls, their coating systems and application, and their quality control and testing requirements.

However the main means of avoidance of SCC is to control the environment.

There was a lively question and answer session, with interesting contributions from the audience and the meeting was closed with a vote of thanks and a presentation to the speaker.
Industry News

CONCRETE SURFACE PROTECTION SYSTEM USED IN KRK BRIDGE PRESERVATION PROJECT!

The Krk Bridge is a reinforced concrete arch bridge connecting the Croatian island of Krk to the mainland and carrying over a million vehicles per year. The longer of the bridge’s two arches is the longest concrete arch in the world outside of China. The Krk Bridge requires constant monitoring and maintenance due to its environment, the main problems being strong winds as well as corrosion from salt which accumulates on the surface.

According to Cortec, a field investigation of the current condition revealed that the concrete was mostly contaminated to the depth of the main reinforcement. The existing contaminated concrete was removed to this depth, and the rebars cleaned. A repair mortar was then applied, and the clean concrete surface treated with Cortec MCI® 2020, a surface applied corrosion inhibitor, designed to migrate through concrete structures and seek out the steel reinforcement bars and provide protection from further corrosion.

UP-COMING CONFERENCES/EXHIBITIONS

EUROCORR 2019 – SEVILLE, SPAIN – 9-13 SEPTEMBER 2019

The annual EUROCORR corrosion congress is being organised this year by the Spanish Materials Society (SOCIEMAT), together with EFC and DECHHEMA, and its theme is “New times, new materials, new corrosion challenges”.

There will be special joint sessions involving two or more Working Groups, in addition to the traditional EUROCORR sessions, and a complete listing of the topics, can be found at, https://eurocorr.org/EUROCORR+2019/Sessions.html

The Plenary speakers are confirmed as, Prof. Manuel Morcillo, Prof. Oscar R. Mattos, Prof. Alicia Valero, Prof. X. Ramón Nóvoa, and their CVs, lecture titles and abstracts, can be found at, http://eurocorr2019.org/plenary-lectures/

There will be a Microbial Corrosion Course on 9 September at the Sevilla Novotel hotel, which will cover, electrochemical and microbial fundamentals of bio-corrosion. This course is aimed at graduate students, beginners and more experienced scientists working in academic or industrial environments who are interested in an approach to microbial corrosion. For further information about the courses and registration, please refer to: http://eurocorr2019.org/courses/

For general information concerning EUROCORR 2019, please visit the congress website at: http://www.eurocorr2019.org.

PDA Europe Annual Conference and Exhibition, 21-22 November, 2019. Brussels, Belgium

This event is a unique forum in Europe for all those involved in the field of Polyurea coatings, and the 2-day event is packed with presentations, interactive sessions, education courses, spray gun workshop, table top exhibition and networking opportunities.

The event will be held at the Crowne Plaza hotel, Brussels, which is 5 minute walk from Brussels North with direct train from/to Brussels Airport every 15 minutes.

Full details will be available shortly, and further information, including sponsorship and exhibiting can be obtained from, info@pda-europe.org.

PaintExpo

8th Trade Fair for Industrial Coating Technologies will again be held at the Karlsruhe Exhibition Centre. The PaintExpo exhibition programme covers all industrial coating technologies from powder coating, through liquid and UV applied systems, to coil and in-mould coatings. The exhibiting companies will present innovations, technologies, processes and services for designing, running and optimising processes in order to meet the great demands placed upon quality and flexibility, as well as material, energy and cost efficiency, for the painting and coating of components made of metals, plastics, wood, wooden materials, glass, and material combinations.

Further information, the entire exhibition portfolio and a preliminary exhibitor list are available at www.paintexpo.com.
**New System for Corrosion Under Insulation (CUI) Monitoring and Prediction**

CorrosionRADAR is pioneering a novel Corrosion Under Insulation (CUI) monitoring technology for oil and gas, and other industries. A spin-out of Cranfield University, it aims to support a move away from reactive risk-based inspection programmes to predictive corrosion management, supporting digitisation initiatives for Industry 4.0.

According to the company, it has developed an automated monitoring and predictive analytics system to monitor CUI, using an innovative distributed sensor system. The novel sensor is permanently mounted next to the pipe, under the insulation, and exposed to the same environment as the asset external surface. An electromagnetic signal is applied to the sensor using the permanently installed electronics, and then proprietary algorithms can be used to determine the location of any corrosion. The system can detect corrosion within a range of several hundred metres.

CorrosionRADAR engaged with the condition monitoring research group at the School of Engineering, Robert Gordon University, Aberdeen. Using a specially designed laboratory-scale rig deployed within an existing corrosion test chamber at the University, the team developed a methodology, using an electrochemical technique, to analyse, corrosion rate and corrosion correlation of various metals under different test cognitions, such as at different temperatures, with different electrolyte solutions, including the effect of sea water on different sensor designs and the importance of the distance between the pipe wall and the sensor.

With the project completed, CorrosionRADAR is now undertaking further R&D collaboration in partnership with OGIC and researchers at Scottish universities, on different design elements of its corrosion and moisture sensor. It has also been working with the Innovation Centre for Sensing and Imaging Systems (CENSIS) on the integration of its corrosion and moisture systems with Internet of Things (IoT) infrastructure.

**New software for corrosion rate estimation and materials selection**

Larkton Ltd, a digital transformation, software design, and corrosion and materials engineering consultancy, has launched Larkton CM corrosion rate estimation and materials selection software. To achieve a new standard in corrosion analysis and materials selection, carbon dioxide and hydrogen sulphide corrosion models and experimental data have been re-analysed, and industry experience and inspection information have been reviewed. The development team also revisited the business processes and needs of corrosion and materials engineers focusing on efficiency and productivity improvement.

According to the company, Larkton CM software gives consistent outputs when tested against legacy corrosion models using the same limited inputs. However, it also offers the option of inputting more detailed data for deeper analysis and greater accuracy. Materials selection options are provided for a wide range of the components used in facilities, pipelines and wells to give a comprehensive output, including material choices for downhole equipment.

**LATEST LITERATURE**

**Corrosion and Materials in Hydrocarbon Production; A Compendium of Operational and Engineering Aspects**

As part of ASME Press and Wiley, Bijan Kermani and Don Harrop, with the help of many prominent engineers, have produced a book on engineering aspects of corrosion and materials in upstream hydrocarbon production. The book is a compendium of technical information on corrosion threats from drilling to production and transportation. It captures and provides solutions via four principal themes focused on upstream hydrocarbon production:

- Outlining key corrosion threats, both internal and external, and means of inspection, monitoring, control and management.
- Providing necessary background on types and nature of materials used for the construction of CAPEX intensive facilities.
- Underlining current and future challenges that the industry sector is facing with some steers towards respective management and technical solutions.
- Implementation of effective and progressive materials' optimisation, corrosion mitigation methods and corrosion and integrity management strategy.

The final chapter considers the future outlook in energy demand and supply, translating these into technology challenges facing the hydrocarbon production industry sector which in turn shapes materials and corrosion technology themes necessary to deliver business success and continuously improving safety, security and minimising impact on the environment.

The book is intended to be suitable for both practicing materials and corrosion engineers working in hydrocarbon production, as well as those entering the area who may not be fully familiar with the subject. It is not a textbook, rather a practical reference source to steer design and operations engineers to currently established best practice drawn on over 500 years cumulative field and engineering experience.

The book can be obtained through normal on-line channels.
Cathodic Protection for Reinforced Concrete Structures

Paul M. Chess, CRC Press, ISBN 9781138477278, Hardback, £54.00

This book is aimed at specialist contractors, large consultant companies and owners of concrete structures suffering from corrosion damaged. It discusses the causes of corrosion, briefly covers the history of CP use in concrete structures and examines the current use of Impressed Current and Galvanic Anode systems. The book also highlights the differences in protection obtained from these systems, and looks at ways where performance can be improved in the future. As an example there are details given of the operational data from impressed current and galvanic systems on four different structures, which show the disparity in the amount of protection obtained. There are useful lists of references at the end of each chapter as sources of additonal information.

The author has a wealth of experience in this field. He was formally MD of Cathodic Protection International, and is currently MD of Corrosion Remediation Ltd.

Living Iron

By Vanessa Everts and Pauline van Lynden, and published by Visual Legacy.

This is a fascinating book, an amalgam of stunning photographs and explanatory text on the subject of iron and steel, its origins, history, and everyday uses. The book describes how iron is everywhere around us - it is vital for our organs and blood, and without it there would be no cars, ships, railways or bridges etc., and demonstrates this through photographs. It draws the reader’s attention to where iron and steel can be seen nowadays, even in places which initially go un-noticed, or which are taken for granted. Of course a book on these metals would not be complete without discussing rust and its very different faces. There are excellent chapters on steel-making, the recycling of scrap iron and steel, and a chapter on the history of the ‘tin’ can from the 1800s to the present day. The authors already have best sellers behind them, and have used the same easy to read format in this book to convey to the reader the importance of these metals in everyday life, and hence the book would be of interest to both technical and non-technical readers alike.

The book is available from all good book shops, price £36.

NEW EDITION OF POLYURETHANES TEXTBOOK

The well-known textbook, Polyurethanes – Coatings Adhesives and Sealants, by authors Hans-Ulrich Meier-Westhues, Karsten Danielmeier, Peter Krupp, and Edward Squiller, is now available in the second revised edition. The book will give readers an overview of the chemistry and various possible application fields of polyurethanes, while specialists will value the insight on current trends and changes.

The chemistry of polyurethane coatings is of great significance in many applications worldwide. Moreover, their development potential has yet to be fully exhausted by any means. New applications are being identified and the product range will be further developed.

The book provides a comprehensive overview of the chemistry and the various possible application fields of polyurethanes. It starts by illustrating the principles of polyurethane chemistry, enabling the reader to understand the current significances of many applications and special developments. Newcomers learn about the key concepts of polyurethane chemistry and the main application technologies, while experienced specialists will value the insights on current trends and changes.

The 445 pages book is available in printed and e-book forms, and can be ordered online from, https://www.european-coatings.com/Publications, price €159.00.

STANDARDS UP-DATE ISO

These documents have obtained substantial support within the appropriate ISO technical committees during the past two months, and have been submitted to the ISO member bodies for voting or formal approval.

ISO/FDIS 2808 Paints and varnishes — Determination of film thickness (revision of 2007 standard)


ISO/DIS 13076 Paints and varnishes — Lighting and procedure for visual assessments of coatings (revision of 2012 standard)

ISO/FDIS 11124-5 Preparation of steel substrates before application of paints and related products — Specifications for metallic blast-cleaning abrasives — Part 5: Cut steel wire

ISO/DIS 14713-2 Zinc coatings — Guidelines and recommendations for the protection against corrosion of iron and steel in structures — Part 2: Hot dip galvanizing (revision of 2009 standard)

ISO/FDIS 19000 Petroleum and natural gas industries — General requirements for offshore structures (revision of 2013 standard)

ISO/FDIS 19001-9.2 Petroleum and natural gas industries — Specific requirements for offshore structures — Part 9: Structural integrity management

ISO/FDIS 22557 Paints and varnishes — Scratch test using a spring-loaded pen

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ISO/DIS 26202 Magnesium and magnesium alloys — Magnesium alloys for cast anodes (revision of 2007 standard)

New International Standards published during the last two months

ISO 2812-3 Paints and varnishes — Determination of resistance to liquids — Part 3: Method using an absorbent medium


ISO 15549 Non-destructive testing — Eddy current testing — General principles

ISO 15708-1 Non-destructive testing — Radiation methods for computed tomography — Part 1: Terminology

ISO 15708-2 Non-destructive testing — Radiation methods for computed tomography — Part 2: Principles, equipment and samples

ISO 15708-3 Non-destructive testing — Radiation methods for computed tomography — Part 3: Operation and interpretation

ISO 21809-11 Petroleum and natural gas industries — External corrosion protection of metallic structures — Part 11: Coatings for in-field application, coating repairs and rehabilitation

CEN Standards issued within the last two months

CEN/TS 17331 Construction products: Assessment of release of dangerous substances - Content of organic substances - Methods for extraction and analysis

This document specifies existing methods for the determination of the content of specific organic substances in construction products. Construction products include, e.g. mineral-based products, bituminous products, wood-based products, polymer-based products and metals. This document includes analytical methods for all matrices except metals.

CEN/TS 17332 Construction products: Assessment of release of dangerous substances - Analysis of organic substances in eluates. This includes mineral-based products, bituminous products, wood-based products, polymer-based products and metals. This document includes analytical methods for all matrices except metals. The selection of the method to be applied is based on the product matrix and the required sensitivity.

ENERGY

EN 13480-1:2017/A1 Metallic industrial piping - Part 1: General

This European Standard specifies the requirements for industrial piping systems and supports, including safety systems, made of metallic materials with a view to ensure safe operation. It is applicable to metallic piping above ground, ducted or buried, irrespective of pressure.


This European Standard specifies requirements for industrial piping either totally buried or partly buried and partly run in sleeves or similar protection. It is used in conjunction with the other six parts of EN 13480. Operating temperature is up to 75 °C, and for higher temperatures reference should be made to EN 13041.

EN 689:2018+AC Workplace exposure — Measurement of exposure by inhalation to chemical agents — Strategy for testing compliance with occupational exposure limit values


to combat corrosion

Innovative Products

NEW HIGH PERFORMANCE AEROSOL-DELIVERED COATING TO COMBAT CORROSION

Corrocoat, the Leeds based leader in anti-corrosion coatings, has announced the release of an aerosol-delivered high performance surface tolerant coating system. Supplied in a convenient, easy to use, single pack 400ml aerosol, application is as simple as breaking the internal seal, shaking the contents and its ready to use. According to the company, there is no need for scales, mixing containers, mixers, cleaning solvents, brushes or spray equipment.

It is based on Corrocoat’s proven Plasmet ZF materials and specially formulated for this application technology. The aerosol contains a high performance glassflake and MIO filled two pack epoxy, with both passivating and rust conversion properties.

With a useable life of many hours and free, easy to change additional nozzles supplied with each kit, the Plasmet ZF aerosol offers a tough, durable coating, ideally suited for small areas of coating damage, rust spotting, small areas of corrosion damage, repairs where a coating has been removed for inspection and many more, concluded the company.

Cortec has launched CorroLogic® CorrPlug® pipe ends, used to cap and protect against physical damage and intrusion of foreign objects during storage and shipping. The pipe caps are formed from thick-wall black polyethylene incorporating VpCI® vapour phase corrosion inhibitor to protect pipe threads, pipe ends, and other tubular objects from corrosion, mechanical damage, and contamination during transit, handling, and storage. According to the company, the caps are specially designed for easy installation and removal and offer protection right to the last pipe thread, which can help eliminate the extra work that might otherwise be needed to be clean the end before being joined together. The pipe caps are made to order in most standard NPT pipe sizes ranging from 0.25 to 64 inches (0.6 cm to 1.6 m) in diameter, and are suitable for carbon steel, stainless steel, copper, brass, and aluminium.
NEW TOPCOAT FOR OFFSHORE USE

Hempel has launched a highly flexible water repellent topcoat, Hempatop Repel 800, which according to the company offers enhanced corrosion protection by actively repelling water from the coated surface. By enabling the use of fewer coating layers, this solution for offshore assets and installations can be applied faster and lasts longer than conventional coatings solutions, saving owners time and money.

For optimum protection, Hempatop Repel 800 is used in combination with Hempel’s Avantguard® 770 zinc primer. The two products work together to create an extremely robust anti-corrosive system. This unique two-coat system requires one coat less than standard protective coatings solutions for offshore installations and lasts significantly longer, simplifying construction and maintenance of offshore assets, and reducing costs for owners.

The new coating meets all the test requirements of ISO 12944:2018 Part 9 for a CX category, is prequalified for NORSOK M-501 Ed. 6, System 1, and has proven adhesion retention and mechanical performance after 14 months extended cyclical aging testing and 10 months condensation testing, concluded the company.

ARTIFICIAL INTELLIGENCE-ENABLED CORROSION DETECTION

ABS, Google Cloud and SoftServe have completed a pilot project applying artificial intelligence (AI) models to detect levels of corrosion and coating breakdown on ships and offshore structures.

According to ABS, the project successfully demonstrated the accuracy of AI in detecting and assessing structural anomalies commonly found during visual inspection. AI techniques could then be further used to analyse images over time to understand corrosion and coating breakdown trends.

ABS Chairman, President and CEO, Christopher J. Wiernicki, stated that “Digital innovation in AI will change how surveys and maintenance strategies are executed, driving more condition-based approaches to class and maintenance. We are building a future in which digital tools can remotely assess the condition of a ship or offshore unit, and automatically detect and measure coating breakdown and other structural issues, improving safety and reliability.”

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Chemical Attack and Cementitious Coatings for Concrete Repair and Protection

Graham James OBE and Chris Lloyd, AkzoNobel

Concrete deterioration exists on a global scale and can severely affect the durability of reinforced concrete structures. The primary causes of chemical attack on concrete include those of chloride ion penetration, sulphate attack and carbonation. This article briefly describes these various modes of degradation, discusses the technical advances in cementitious coating technology, and gives some examples of their use.

Chloride Attack

A major cause of damage to reinforced concrete exposed to chlorides is corrosion of the steel reinforcement, especially for structures in marine, highway and other chloride-laden environments, including buildings in proximity to the coastline. Chloride ion penetration leads to the aggressive corrosion of steel reinforcement, even in alkaline concrete, causing cracking and spalling, and in the very worst cases structural failure.

The steel reinforcement is protected against corrosion by the inherent highly alkaline environment of the concrete created by the generation of calcium hydroxide from the cement hydration. This results in the formation of a passivating layer on the embedded steel surface. As long as this surface film is maintained, the steel remains protected from corrosion. However, when concrete structures are repeatedly exposed to airborne chlorides or salt spray, due to their molecular size, chloride ions can penetrate the pores of the concrete, eventually reaching the steel, breaking down this protective layer and causing corrosion. In the case of marine structures, the most rapid corrosion occurs in the splash zone where the intermittently wet and dry conditions exacerbate the penetration of chlorides and where there is enough oxygen, and sufficient moisture present to increase the electrical conductivity of the concrete, to facilitate the corrosion process, leading to an aggressive form of localised attack called pitting corrosion, which can potentially cause rapid loss of steel section and major cracking and spalling of concrete, thereby compromising structural integrity.

In tidal and submerged zones, where the concrete is saturated in seawater and oxygen levels are limited, the concrete pore structure is constantly filled with water. Nevertheless, in areas where there is low concrete cover, particularly in the splash zone, corrosion can still occur, causing a challenge for its reinstatement.

The depth and quality of the cover concrete is vital, as the relatively thin layer of concrete protects the reinforcing steel from corrosion by maintaining an alkaline environment and preventing the ingress of chloride ions and the other aggressive species which promote corrosion. This is recognised in European Standards, with EN 206 defining the concrete mix design, and EN 10080 giving the requirements for cover.

Whilst marine structures are subject to constant exposure to chlorides, highway structures are similarly affected during the winter periods when de-icing salts are used. These readily dissolve in snow or rain water and the resultant highly...
concentrated salt solution, or spray from vehicles, can pose a threat to concrete structures within the vicinity of a highway, with the potential for chloride ion ingress, exacerbated by repeated wetting and drying cycles.

As soon as low concrete cover has been identified, it is important to take swift action, otherwise the lack of protection of the re-bars will lead to premature de-passivation of the steel and subsequent corrosion. Inadequate concrete cover will not only speed up the damaging effects of carbonation but also allow even more rapid ingress of chlorides, moisture and oxygen to reach the steel surface. At worst, sections of concrete may need to be demolished, or partial recasting may need to be carried out, however both these options are very costly and often difficult to carry out.

**Carbonation Attack**

Carbonation, which causes the breakdown of the alkaline environment surrounding steel reinforcement, is another major problem in untreated concrete infrastructures in atmospheric service. Carbon dioxide migrates through cracks and pores in concrete, reducing the pH of the alkaline environment from 12-13 to around 9, inevitably leading to corrosion and concrete spalling.

As detailed in an earlier paragraph, reinforced concrete buildings and other assets suffer from exposure to airborne chlorides in coastal environments. Without suitable protection from the elements, carbonation and chloride ingress combine to form a dangerous cocktail which, in addition to the effects of weathering, can soon impact on durability and the intended design life.

**Water Facilities**

**Waste water facilities**

In terms of reinforced concrete in waste water facilities, the most widely feared mechanism for the erosion of concrete in sewerage systems is bacterial in origin. Normal domestic sewage is slightly alkaline and does not contain sulphates in sufficient concentrations to attack concrete directly. The damage which occurs is due to sulphuric acid produced by certain bacteria as a result of changes occurring in the sewage.

When conditions are such that oxygen in the sewage becomes depleted, anaerobic organisms, which do not use atmospheric oxygen, obtain their requirements for growth from dissolved salts. This has the effect of chemically reducing sulphates and other organic sulphur compounds in the sewage to form hydrogen sulphide.

Contrary to popular belief, the gas itself does not directly attack concrete, but it will readily dissolve in moisture particularly on the crown or soffit of sewers and on the walls above liquid level, and is then oxidised to sulphuric acid by aerobic organisms of the Thiobacillus species. Research conducted in the USA indicated the concentration of sulphuric acid generated within sewerage systems peaks at circa 5%, a level which will readily attack normal concrete. There are various factors which determine the precise concentration but high temperatures are known to greatly encourage bacterial growth.

**Reservoirs - Soft Water Attack**

Soft water is defined as water deficient in calcium and magnesium salts, and can be a major problem in reservoirs storing high moorland or mountain water. Because of its pure nature, it effectively acts as a high performance solvent, dissolving the lime that is formed either as a by-product of the cement hydration process, or is present in limestone aggregates, resulting in deterioration of the concrete.

Some soft waters also contain dissolved carbon dioxide which produces weak carbonic acid. Other organic acids naturally occur in soil and ground waters from rotting vegetation such as humic acid, which originates from peat. These reduce the pH to below 5.0, thus making the water highly aggressive and undermining the integrity of concrete by weakening the matrix. With increased permeability, the concrete is vulnerable to advancing deterioration as the pore structure is opened to more acid ingress, ultimately resulting in breakdown of the substrate and failure of the structure to contain water.

There are cementitious coatings available that exhibit excellent resistance to attack from soft water. Key products incorporate pozzolanic materials and microsilica. Pozzolans react with the lime to form high levels of insoluble calcium silicate hydrates with very good chemical resistance. Microsilica effectively ‘mops up’ lime and affords enhanced resistance to chemical attack. Furthermore, the polymers incorporated into these materials form a protective film on the surfaces of the hydrates, subsequently enhancing the chemical resistance even further. Key products can also withstand immersed conditions without detrimental effect and have been specified for many contracts where water authorities have experienced specific problems with soft water attack. As a result, the concrete integrity is maintained, and the re-bars protected.

As an example, cementitious coatings were used to repair over 30 reservoirs as part of the Northern Ireland Framework Rehabilitation Programme. Virtually all of the structures were suffering from soft water attack and in some cases, the attack was so severe that repair mortars were applied first to reinstate the integrity of the substrate, before the protective cementitious coating was applied.

**Protective Coating Technology**

Over the last 30 years, major continual technical advances have taken place in protective coating technology. In particular, significant progress has been made by certain manufacturers of decorative anti-carbonation coatings to offer high levels of performance with a paint film thickness that would not have been possible even just 10 years ago. In the field of engineered protection for heavy duty applications, the latest cementitious coatings have allowed extended service life solutions to be implemented in conditions which are impractical for traditional anti-carbonation systems.

The latest generation of cementitious coatings can overcome many of the limitations of organic resin-based systems and can be applied to damp substrates without risk of osmotic blistering. Offering high resistance to wash-out, they withstand immersion within as little as 60 minutes after placing. Their high build application and rapid cure makes them less susceptible to damage, especially immediately after application and during their early life. Furthermore, as water-based systems, the environmental credentials are attractive, posing minimal risk
in application with all equipment being washed in water after use. Testing structures suffering from carbonation which have been treated with such cementitious coatings, showed that the concrete will re-alkalise, and the depth of carbonation is effectively reduced providing further protection to the reinforcement, particularly in the presence of chlorides.

Cementitious coatings can be directly applied to reinforced concrete structures which are either approaching the end of their design life or which have suffered from premature degradation. These high performance coatings can also be used on new build structures as part of the original design or to provide a solution to non-conformance with specification. Where critical structures such as bridges are being built in onerous marine environments, consultants have recognised the benefits of such coatings to help ensure the 120 year design life is achieved, reducing the risk of costly future maintenance.

With regards to repair projects, any defective concrete can be cut out and the steel reinforcement protected with a corrosion preventative coating, prior to the application of concrete repair mortars and protective coatings.

One product which is frequently specified on both existing and new structures to waterproof, reinstate cover and provide an effective barrier to chloride ingress, is based on a two component, waterborne cementitious modified polymer coating which was originally introduced in 1985, and it still remains one of the most effective products for providing structural protection against chloride attack. A 2mm coating of this is equivalent to 100mm of good quality concrete cover.

Independent testing carried out at the VINCI Construction Technology Centre in Bedfordshire has confirmed that this product can provide an effective barrier against chlorides for many years. In 1988, a 2mm thick film was applied to a concrete slice and sealed in a chloride ion diffusion cell, and 30 years later was still providing full protection. Continuous testing carried out in the laboratory showed that the barrier properties of the product have remained the same throughout this test period, a testament to product’s long-lasting performance.

High performance cementitious coatings are widely specified on both existing and new structures in coastal environments, highways and the water and wastewater industry. They can also provide an alternative to the recasting or demolition of precast and in-situ reinforced concrete, reinforcing the substrate with the durability to achieve its specified design life.

**Typical Case Histories**

As part of a major £16 million upgrade of a south coast wastewater treatment works, a proprietary concrete repair material was chosen to refurbish an underground inlet chamber at the plant. Almost 140 tonnes were applied over a six month period by a specialist asset maintenance contractor.

Dating back to 1997, the treatment works is located on the seafront and serves a population of circa 140,000 people, the vast majority of the works is located underground, beneath a fortress-style building. Up to 74 million litres of wastewater is pumped in and treated every day almost entirely out of sight.

The concrete repair work was carried out beneath ground level in extremely arduous conditions. The project involved the refurbishment of the underground inlet channel that receives wastewater flows, as the concrete had deteriorated because of attack from sulphuric acid due to the presence of hydrogen sulphide gas. The application was carried out at night when flows were low.

The repair system devised for the project comprised a dry spray application of a single coat fibre-reinforced high build repair mortar (Intercrete 4801) followed by a final coat of a two component epoxy and polymer modified cementitious coating (Intercrete 4840). This combined system was chosen on the basis of the rapid curing properties, and speed of reinstatement between application of the mortar and coating, as there was no need for a skim coat due to the high quality finish of the mortar. The system also minimises the environmental impact due to the fact that both products are water-based, ultra-low odour and solvent-free, making them safe to apply even whilst facilities are in operation.

The contractor used hydro demolition to remove damaged concrete, before a dry spray application of the waterproof, class R4 mortar. Following this the cementitious coating was applied at a total dry film thickness of 2mm achieved in 2 coats.

In another example, Doha Corniche is a waterfront promenade extending for 10km along Doha Bay in the capital city of Qatar, Doha. Formed following extensive dredging work carried out during the late 1970s and early 1980s which reshaped Doha’s coastline, the Corniche is now popular among walkers, bikers and joggers. Protection from high seas is provided by a concrete breakwater which suffers from erosion from wave action and chloride induced corrosion of the steel reinforcement.

When a new 500 metre precast concrete extension was constructed, the use of a chloride barrier was stipulated to extend the design life. Following consideration of a number of coating systems and intense testing, the Ministry of Municipal Affairs and Agriculture specified a 2mm layer of a two component epoxy and polymer modified cementitious coating (Intercrete 4840). This was applied in two coats by spray and bonded intimately to the concrete. This should provide a durable waterproof layer which will not break down under the harsh direct sunlight.
Doha Corniche.
NACE 2019 – Report by the ICorr Young Engineers Competition Winners

The prize for the winning team of The Institute of Corrosion’s Young Engineer Competition was a visit to the NACE 2019 Corrosion Conference and Expo in Nashville, USA. The following report by the team highlights a selection of their learnings from the conference on the theme of ‘Corrosion Mechanisms, Novel Materials and New Coating Applications for Managing and Mitigating Corrosion in Harsh Environments’.

The winning team comprised of, Danny Burkle from LBBC Baskerville, Caroline Earl from Fluor Corporation, Oliver Smith and Jessica Easton from AkzoNobel.

In 2016, NACE International released the International Measures of Prevention, Application, and Economics of Corrosion Technologies (IMPACT) study which estimated the current global cost of corrosion to be US $2.5 trillion, which is equivalent to 3.4% of the global GDP. The study estimated that savings on an annual global basis could be up to $875 billion (35%) through the use of available corrosion control practices. To achieve the full extent of these savings, corrosion management and its integration into an organisation’s management system must be accomplished by implementing appropriate corrosion management systems.

Corrosion Mechanisms and Failures of Corrosion Resistant Alloys

One method of corrosion management is the use of Corrosion Resistant Alloys (CRAs), which were initially designed to prevent carbon dioxide (CO2) corrosion in pipelines. Recently advances have been oriented towards increasing the corrosion resistance of these materials to other corrosion mechanisms as many industries including Oil and Gas, Chemical Processing, Geothermal and Carbon Capture and Storage, are now facing increasingly harsh conditions, and materials are being exposed to aggressive environments beyond the means of their capabilities, resulting in a vast number of corrosion failures. As the operating conditions and the produced fluids become more aggressive, the use of CRAs are in the forefront. However, despite decades of research and development, with numerous publications and advancements in material technologies, hydrogen damage and embrittlement in its various forms, the most prominent being Hydrogen Assisted Cracking (HAC) and Stress Corrosion Cracking (SCC), continue to have a major impact on the material selection process and the integrity of existing assets across such industries. Therefore, and understandably, this hot topic has captured the attention of some of the most experienced engineers, scientists and researchers across these industries. This topic received a lot of interest at Corrosion 2019, which was demonstrated during many symposiums, including the “CO2/H2S Corrosion in Wet Hydrocarbon Containing Environments” symposium and the “Recent Experiences with Nickel, Titanium, Zirconium and other Corrosion Resistant Alloys” symposium. A fundamental understanding of HAC and SCC is crucial across many industries so that the risk of corrosion can be suitably managed and controlled. On that basis, a series of papers contributing to the knowledge gap were presented, and a selection of this work is discussed below.

Precipitation Hardened (PH) nickel alloys in the form of UNS N07718, UNS N07716 and UNS N07725 are commonly selected for equipment used for downhole, wellhead, subsea...
and ‘christmas tree’ applications due to their combinations of high strength, excellent thermal stability and purpose-built corrosion resistance. However, as reported by Morana, et al., BP Exploration & Production Co Ltd., in their work entitled “On the Susceptibility of Precipitation Hardened Nickel Alloys to Hydrogen Assisted Cracking”, several high-profile failures have occurred in these alloys used for tubing hangers, cross-overs, subsea bolts and safety valves. These failures were a result of HAC through embrittlement due to atomic hydrogen absorption into the alloy matrix. The authors concluded that in all cases, the failed components were subject to hydrogen charging either during equipment manufacturing (e.g. during electroplating), or in service (e.g. due to aggressive fluids or to galvanic coupling). The failed components exhibited failure modes in the form of either intergranular, transgranular or mixed intergranular/transgranular cracking, with evidence of embrittlement through traces of hydrogen found in the material’s microstructure in the range of 2 – 10 ppm. Failure in the cases investigated always occurred at high stressed locations. Their work concluded that both UNS N07725 and UNS N07718 may not be suitable for applications where hydrogen charging is credible and where stresses can be high.

This work also highlighted that the use of API Specification 6A718, which had been produced by manufacturers and operators from previous experiences and lessons learned, better ensures HAC-resistance by close control of microstructure and all influencing process steps. For example, the chemistry of the CRA is restricted to make the most deleterious phase (δ phase) less likely, and metallographic assessment assures that the phases present (including δ phase) are not distributed deleteriously. There have been no reported HAC failures of UNS N07718 that meet the API Spec 6A718S. Some other PH nickel alloys also have had no published issues with hydrogen embrittlement, for example UNS N09925 with a specified minimum yield strength (SMYS) of 110 ksi. The relationships between high PREN (Pitting Resistance Equivalent Number) alloys and HAC were highlighted and attributed to the higher molybdenum content provoking segregation phenomena and δ-phase promotion at the grain boundaries. This work was extended to API 6ACRA for other PH nickel alloys, such as grades UNS N06625 (110ksi), UNS N06005 (110ksi) and UNS N07718 (150ksi). However, failures with UNS N07718 tubing and casing hanger failure, and UNS N07725 (120 ksi) cross-over failure, have occurred despite meeting API 6ACRA, highlighting that limiting the SMYS alone is not the solution. Again failures were attributed to the hydrogen adsorbed and its interaction with δ-phase at grain boundaries. It was proposed that the alloy metallurgy grain boundaries must be free from continuous secondary phases.

In another study involving nickel alloy, “Materials Performance Challenges in Oil and Gas Production Wells” by Saithala, et al. of the Petroleum Development of Oman, a UNS N07718 alloy tubing hanger installed in a sour oil well had experienced failure after 15 years in service. Given that the use of this material was commissioned, and in-service, prior to the latest API standard (API 6ACRA), an investigation into the failure was carried out which confirmed that the chemical composition of the material was acceptable in relation to the latest standard. However, the hardness results of the material, and the material microstructure, were shown to be out of specification and not compliant with the requirements for UNS N07718 alloy as outlined in API standard 6ACRA. In addition to this, the authors concluded that galvanic coupling between the carbon steel tubing and the N07718 tubing hanger, in the presence of increasing water content, likely resulted in hydrogen embrittlement in the hanger due to its susceptible microstructure and highlighted the importance that UNS N07718 alloy should be fabricated in accordance with API 6ACRA to avoid any reoccurrence of such failure.

Cathodic protection (CP) was shown to reduce the Ultimate Tensile Stress (UTS) due to brittle fracture mechanisms in, “Hydrogen Embrittlement of High Strength Precipitation Hardenable Nickel Alloy” by Dodge, et al. of TWI Ltd. Hydrogen also reduces the UTS, which is attributed to hydrogen diffusing to areas of high localised strain and plastically deformed regions. Brittle intergranular facets were found to be populated by slip bands, and nucleation sites for micror, nano-void, formation, which coalesce under strain resulting in hydrogen crack propagation. The presentation concluded that hydrogen embrittlement is a high-strain and dislocation-activated plastic process.

Another common form of corrosion damage observed in CRAs is intergranular corrosion due to sensitisation. One such example described in “CRA Failures in Refining Operations” by authors from Pinnacle Advanced Technologies, Texas A&M University and Hunt Refining Company, was the failure upon start-up of UNS N06625 flexible hoses located at the inlet of a reformer in a hydrogen plant. It was found that the materials were heavily sensitised with embrittling phases present at the austenite grain
boundaries. The microstructure of all PH nickel alloys is based upon an austenitic (γ) matrix solid-solution strengthened by elements like Cr, Fe and Nb. Some of these alloys also contain γ′ (Ni3Al/Ti) and γ″ (Ni3Nb) strengthening precipitates dispersed within the matrix, developed during suitable solution and ageing heat treatments. Other phases are possible in these alloys, most significantly the non-strengthening δ phase (Ni5Nb), which needs to be suppressed while maintaining sufficient stability against sensitisation, thereby reducing susceptibility to intergranular corrosion. However, improper annealing and processing can inhibit niobium carbide formation making carbon more available for Cr carbide precipitation, and further sensitisation of the material.

Recent Advancements in Corrosion Resistant Alloys

Extreme operating conditions and more aggressive produced fluids as seen in the Chemical Process Industry (CPI) have driven the evolution of CRA materials. However, failures related to hydrogen stress cracking, sulphide stress cracking, and chloride stress cracking can limit the application of such alloys, as discussed previously. Hence, in industries with such extreme and corrosive environments, any material is vulnerable to corrosion attack.

Ajit Mishra of Haynes International, Inc., assessed a range of materials in acid containing fluids in “Materials Performance in an Oxidizing Acid and Corrosive Solution containing Oxidants”. The focus of the work was to understand how a range of stainless steels, primarily in oxidizing acid and acidic solutions containing oxidants. The author attempted to correlate the corrosion performance of the alloys to their alloying elements and contents in acid solutions. Corrosion test date were presented on HASTELLOY® and other CRAs. The corrosion data presented suggested that in oxidizing acids and complex oxidizing-reducing solutions, UNS N06035 (Ni-35Cr-8Mo) exhibits a remarkably high corrosion resistance in comparison to existing nickel and iron-based alloys. This is primarily due to its high Cr content (33%). The work highlighted that the amount of Cr needed in a Ni-alloy, to handle an aqueous solution containing HNO3 should be > 20 w/w %. This illustrates why a significantly higher corrosion resistance is observed in N06035 (33%) compared to N06200 (23%) and N06022 (22%) in comparison to N10276 (18% Cr) and Ni0382 (15% Cr). However, it was observed that in a reducing acid or mixture of reducing acids, N06035 alloy (containing lowest Mo among the studied alloys) has the highest corrosion rate. Interestingly, the same alloy exhibits the lowest corrosion rate in solutions containing oxidants (such as ferric ion, peroxide) which can be attributed to its high Cr content among the studied alloys. In reducing acids (like HCl and H2SO4), an alloy containing high Mo (or Mo + 0.5W) exhibits high corrosion resistance. In the presence of oxidizing impurities (Fe3+, Cu2+, NO2-, O2-, S2-, SO42- etc.), the material selection process should be focused on material with a high Cr content (> 20).

The changing market demands in the chemical processing and related industries call for new and enhanced performing materials and a new super-austenitic stainless steel alloy designed by Klapper, et al., of Vallourec, to modify UNS N08034 (33Cr-8Mo) with Nb to promote martensite. Vanadium was also added to promote the precipitation of vanadium carbo-nitrides which contribute to the strengthening of the material. The new alloy demonstrated higher corrosion resistance performance than “Super 13Cr 13-5-2” materials, and can be an alternative and cost effective solution to the use of more exotic Super Duplex materials when exposed to environments where the material can be vulnerable to CO2 corrosion (in the form of pitting) or H2S corrosion (in the form of SCC or SSSC).

A slightly different, but increasingly common approach, into improving material performance whilst keeping costs low is, Additive Manufacturing (AM). The term AM describes a variety of techniques in which a base material is consolidated, typically with heat or force, in successive layers to create a solid, 3D object. This method is being introduced into several industrial applications including the oil and industry, with current research efforts focused on demonstrating material performance in demanding oilfield applications. Klapper, et al., of Baker Hughes, investigated the corrosion resistance susceptibility of selectively laser melted UNS N07718 alloy in simulated drilling applications in, “Pitting and Stress Corrosion Cracking Resistance of Additively Manufactured Nickel Alloy UNS N07718 in Chloride-containing Environments”. The pitting and stress corrosion cracking resistance of this alloy in chloride-containing solutions at elevated temperatures, was explored through cyclic potentiodynamic polarization and slow strain rate tests. Based on all the experimental results presented, the AM process has little influence on the corrosion behaviour in the selected test environments that simulated oilfield drilling environments. The use of AM N07718 has thus been deemed positive, and has the potential of reducing machining costs for materials used in demanding environments, whilst maintaining the corrosion resistance of wrought alloy materials.

Another study on AM, “Sensitivity of Localized Corrosion of Additively Manufactured Alloy N06210 in Green death solution” by Dalgo, et al., Hitachi Metals, Ltd. reported on the dependency of pitting and crevice corrosion sensitivity of AM N06210 due to poor surface finish and AM building direction. The authors stated that the AM alloy exhibited slightly higher corrosion rates compared to the wrought alloy, due to the segregation of the chemical components within the microstructure, which are responsible for the reduction in corrosion resistance. However, they reported that the decrease in corrosion resistance is minor and can be disregarded.

The presentations discussed above have shown promise for the use of AM. They highlighted many of the benefits of AM, such as a reduction in lead time, increased design complexity and improved functionality for engineering applications, although it has to be noted that both these presentations also highlighted the importance for further studies in harsher environments to better define the corrosion performance of AM materials.
Novel Coating Systems to Manage Corrosion

As already mentioned, CRAs are used to mitigate corrosion, but their expensive material cost often limits their use, especially in upstream oil and gas applications, where operators require many tonnes of material, with over 90% constructed from low alloy carbon steel due to its mechanical properties and relatively low capital expenditure. Yet, carbon steel is an extremely active material and prone to general and pitting corrosion, especially in the presence of hydrated CO$_2$ and H$_2$S gas, in the process brine. The dominant method of protecting long-distance carbon steel pipelines is cathodic protection (CP). Large CP systems are extremely expensive to install, maintain and replace, and for these reasons, coating systems are used as an additional method of protection for carbon steel from corrosion. There are a number of coating systems commercially available for the mitigation of corrosion (e.g. liquid epoxy, or fusion bonded epoxy - FBE). These coatings, however, are generally not able to resist significant erosive environments and as such another corrosion mitigation method is the use of thermal and cold spray coatings.

One method of utilising the corrosion resistance of CRAs, and the mechanical integrity of carbon steel, whilst keeping costs relatively low, was explored by Shiladitya Paul (TWI) in "Corrosion of carbon steel in supercritical CO$_2$H$_2$S and its mitigation using coatings". The author described the process of coating carbon steel with thermally sprayed CRA coatings. This concept has been researched recently although concerns were expressed due to the likelihood of accelerated corrosion of the underlying carbon steel if the CRA coating was damaged, especially in the presence of H$_2$S, however the presentation by Shiladitya addressed these concerns, and evaluated the performance of thermally sprayed coatings (TSCs) in the form of UNS N10276, UNS N06276 and UNS S31603 alloys, which were sprayed onto carbon steel. Holidays were then purposely drilled to expose the steel substrate and the specimens tested in de-aerated chloride solution saturated with supercritical CO$_2$ and CO$_2$ containing H$_2$S at 40C. It was concluded that Coatings of these alloys can provide a cost-effective corrosion mitigation method for infrastructures likely to be in contact with these materials. However, the long-term performance of the thermally sprayed UNS S31603 coating needs to be evaluated further to establish durability. The presence of CRA coatings can accelerate the corrosion of the underlying carbon steel substrate close to a holiday or defect. Therefore, this highlights the importance of the care that must be taken to ensure that the thermally sprayed CRA layers do not have any through porosity or defects; else, such coatings may accelerate the corrosion of the underlying steel due to galvanic interactions.

Failures of high strength bolting have occurred in offshore drilling equipment creating concerns in the oil and gas industry inspired the work presented by Rosas, et al. (Doxsteel Fasteners) in "Ni-Co Electroplating as a Protection Against Environmental Assisted Cracking of Coated High-Strength Steel Bolts in Sea-water". This study highlighted the reports issued in 2014 and 2016 by the Bureau of Safety and Environmental Enforcement (BSEE) which concluded that hydrogen embrittlement of bolts was being induced by cathodic protection due to sacrificial coatings. Additionally, the American Petroleum Institute (API) recommended the prohibition of sacrificial coatings providing cathodic protection in this application. The Multi-Segment Bolting Task Group Report No.3 (TGR-3) specifically targets zinc plating and recommends finding an alternative due to the internal hydrogen embrittlement (IHE) induced by zinc plating, and environmental hydrogen embrittlement (EHE) induced by the cathodic protection. The work presented addressed the influence of different metallic coatings on the amount of hydrogen present in steel bolting substrates. The authors then related the amount of hydrogen to the extent of hydrogen embrittlement. Different coating systems were applied to steel bolts, zinc plating, zinc-nickel plating and, nickel-cobalt ASTM B694, SC 18, Class 1 electroplating. The results showed that the nickel-cobalt system produced less current, resulting in lower levels of hydrogen permeation and was not affected by the cathodic charging. The presentation concluded that in service conditions, when hydrogen is produced through plating processes and cathodic protection, the carbon steel coated with nickel-cobalt will not suffer hydrogen embrittlement.

Another study from Graphene Applied Materials looked at the development of 'novel' coating systems and at the use of "Green" non-metallic anti-corrosive pigments (calcium oxide-modified silica) in combination with graphene nano-platelets (GNPs), in an effort to eliminate the use of zinc phosphate based materials which, while non-hazardous to humans, some are a marine pollutant. Two grades of graphene nano-platelets were used, differentiated by surface area and morphology, in an industrial environment (ISO 12944, C3) epoxy coating and compared to typical systems containing commercially available anti-corrosive pigments. The main aim of the work was to characterise the mechanisms by which GNPs work as a synergist to other anti-corrosive pigments to allow improvements in coating's anti-corrosive performance. The authors reported that the addition of GNP in the forms used had the ability of providing enhanced corrosion resistance to mild steel. The enhanced corrosion resistance offered by the coating formulation implementing GNPs was a function of the GNP morphology, functionality and interaction with the host resin at one level, and specific interaction with the anti-corrosive pigment at another. Although the exact mechanism leading to the enhanced corrosion protection is unclear, the authors have suggested a complex physiochemical impact by the GNP, which in turn influences the electrochemical behaviour of the pigment.

Summary

Effective integrity management across all industries that suffer from corrosion failures can ensure that the all assets perform effectively and efficiently for the entire duration of their designed life. Implementation of a successful integrity-management process requires the evaluation of all risks associated with corrosion that have the potential to reduce the life of a structure. Therefore, reducing the corrosion risk through an understanding of the different corrosion mechanisms, material developments and mitigation and monitoring techniques, are all key components of maintaining an effective corrosion management strategy, which was exemplified throughout the presentations and discussions at the NACE 2019 Corrosion Conference and Expo.

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Successful Planning and Performance of Cathodic Protection Surveys

Stephen Tate, PG. Dip. Eng. MBA, MICorr, CAN Offshore Ltd

This CP planning focussed paper, is intended to compliment the May/June 2018 Corrosion Management article on the Principles and Practice of Cathodic Protection Monitoring.

Successful Cathodic Protection (CP) systems, whether of the Impressed Current Cathodic Protection (ICCP), Sacrificial Anode Cathodic Protection (SACP) or Hybrid Type, all require regular inputs from both the scheme owner and its neighbouring parties, to maintain their focus and relevancy, to ensure that the CP data collected is both meaningful and meets the needs of all affected parties. SACP & ICCP are methods of CP corrosion mitigation that can be successfully applied to both buried and submerged metallic structures to control corrosion, by establishing them as the cathodic component of an electrochemical cell.

Features and benefits of SACP:
1. Anode connections are also protected.
2. Correct material selection (or in combination with resistors) ensures no over-protection, thus avoiding metal embrittlement and coating disbondment issues.
3. Has reduced CP interference effects on neighbouring structures and limited range.
4. Inexpensive but may not provide LOF – Life of Field Protection.
5. Low power with negligible risk of plant damage due to incorrect connections.
6. No independent electrical supply required.
7. Relatively simple to install, operate and maintain.

ICCP - Impressed Current Cathodic Protection

Impressed Current Cathodic Protection systems may considered as an ‘all-round’ protection system, having the benefit of using (theoretically unlimited) external power sources of various types, to drive the protective current. This makes it possible to protect virtually any structure (often for LOF), regardless of size or current requirements, using long life anode materials and appropriately sized power supplies.

It is mainly used in cases where the required driving voltage is far higher than can be provided by a galvanic system, or there is a need for increased system control, or it has proved impossible to fully electrically isolate from other connected equipment and their copper safety earths. ICCP Systems can offer permanent...
and automated CP protection that aids in preventing galvanic corrosion and electrolysis from occurring, maintaining design corrosion allowances.

Advantages of ICCP:
1. Enhanced lifespan of CP connected equipment (usually for LOF).
2. Maintains structure aesthetics and structure integrity via slimline electrodes or buried/submerged conductive wires.
3. May protect several structures simultaneously (if of sufficient design capacity).
4. Output can be adjusted to suit varying protection demands (either automatically or manually).
5. Usually non-destructive installation without the need for welding.

**UK collaborative forums**

Performing a major CP survey, without prior consultation as to ongoing events and maintenance activities, can often result in disappointing outcomes and wasted effort.

A successful Corrosion Management forum will help prevent this, and can be defined as a 'specially formed' consortium of Primary Operators, represented by their Technical Authorities (TAs), with specific reference to corrosion and its prevention on metallic structures, of inter-plant or inter-dependent facilities.

There are many examples of successful CP collaborations around the UK but perhaps Northern Scotland with its high concentration of energy related Hubs has been most active in this area. Several of these were initiated and chaired by John Thirkettle of Thor Corrosion, who was an ICorr professional member, and to whom much credit is due for their continued success, along with similar Corrosion / CP Forums initiated at Fife, (Mossmorran Processing and Braefoot Bay Liquids Export Terminals) and also for the Bacton Area Gas Facilities in England.

**Advantages of ICCP:**
- Enhanced lifespan of CP connected equipment (usually for LOF).
- Maintains structure aesthetics and structure integrity via slimline electrodes or buried/submerged conductive wires.
- May protect several structures simultaneously (if of sufficient design capacity).
- Output can be adjusted to suit varying protection demands (either automatically or manually).
- Usually non-destructive installation without the need for welding.

**Routing**

For a variety of reasons, CP protected pipelines may share a common routing, or share a routing with other services. Utilities which may, or may not, have CP protection themselves.

Common places for shared routings are:
1. Highway verges.
2. Approaches to and from processing terminals.
3. Approaches to and from pipe bridges across water courses.
4. Areas constrained by natural geology/limited working width.

**Use of Drones**

The use of drones for visual inspection provides benefits such as:
1. Assist in unauthorized security breaches/integrity threats.
2. Easy access to areas that pose health, safety and environmental risk to humans.
3. High levels of safety for personnel.
4. Preventive maintenance planning and optimised production.
5. Provision of high quality images and video - sharp and detailed photographs of defects.
6. Quick on-site deployment of the drone inspection system by authorized and qualified UAV (unmanned aerial vehicle) pilots/inspection personnel.
7. Quick overview and evaluation of hard to reach areas.
8. Overall reduced survey downtime.

A fleet of UAVs can be used to inspect pipelines in very remote locations—swamps, jungles, and other areas where it is preferable to collect CP data remotely, rather than repeatedly sending in personnel and putting them at risk. Increasingly UAVs are deployed in very remote locations—areas where driving in a truck or walking is not possible or feasible for several reasons.
UAVs can fly over the pipelines and collect CP readings on a regular basis, and essentially replace “walking the pipeline” every month or quarter. This ensures that readings are taken regardless of the season, time of day, accessibility of the pipeline, or any other obstacle that could be encountered.

**Joint routes with mixed piping materials:**

The inter-dependency of applied Cathodic Protection should not be under-estimated, or ignored. The combined effects of neighbouring CP schemes may significantly impact on recorded CP potentials at the point of measurement, so that it is critical to be aware of all known CP current / stray current sources, prior to performing a major CP survey.

This particularly applies where there are restrictive criteria, specific to non-standard, or less common metallurgies (not all pipelines are constructed from carbon steel). For example stainless / duplex materials are particularly prone to CP over-protection, and if unduly stressed at welds or at bends, these materials may ultimately crack with resulting loss of integrity and with environmental consequences.

**External Stray Current Interference**

Naturally occurring events must also be taken into account when evaluating overall CP protection status and in the interpretation of data. The timing of such surveys can be critical, especially in more northerly regions.

Peak times for Telluric / Geomagnetic activity are typically during the Spring and Autumn periods (Neep Tides). Magnetic variations from geomagnetic storms will induce an electric field into the Earth and resulting Geo-magnetically induced currents (GICs) that can surge along oil and gas pipelines and high-tension electricity transmission lines via transformer groundings, sometimes greatly destabilising CP potential traces [1].

It is very useful to consult first with such organizations as the British Geological Surveys [2], or other forecasting services such as the Aurora-Service [3]. When such events are expected, then continuous logging devices should be installed at all CP test points.

**CP standards**

A guidance list of international cathodic protection standards is given below but these should always be checked for latest revisions and against operators own standards for any additional requirements:

3. BS EN 12473 “General Principles of Cathodic Protection in Sea Water”
4. BS EN 12954 “Cathodic Protection of Buried and Immersed Metallic Structures – General Principles and Application for Pipelines”
5. BS EN 13174 “Cathodic Protection for Harbour Installations”
8. NACE SP-0169-2007 “Control of External Corrosion on Underground or Submerged Metallic Piping Systems”

**General planning guidelines**

Be aware when planning CP monitoring surveys that:

1. It is necessary to consider in advance all access constraints such as, security fences, landowner consents and vehicular accesses that may hinder performance and completion of some CP survey methods.
2. Unless there are prior agreements in place, then landowners will require advance notification.
3. Where intermediate valve station / ESDV chambers have been installed and CP isolations need to be confirmed, then these areas may be very deep and almost certainly requiring special training for confined space entry.
4. Often the end points of CP schemes may be located within hazardous areas within oil and gas terminals or water pumping stations, with special permit entry and training requirements, which can significantly delay completion of the survey.
5. Lone working should generally be avoided, especially in conditions of bad weather.
6. Survey reporting schedules / pro-formas should be set up in advance to assist accurate and prompt reporting of CP data.
7. CP criteria to be applied, should be agreed in advance with CP scheme owner (s). The boundaries of ‘Acceptable protection / Over-protection and ‘Under-protection’ must be clear prior to reporting commencing.
8. Joint CP schemes where a number of buried pipelines deliberately share CP protection sources, or are influenced by each other’s CP outputs, require special consideration and planning.
9. Enquiries should be made as to what CP related data is routinely / automatically reported from established plant maintenance routines, via SCADA (Supervisory Control and Data Acquisition), or other in-built systems, as this data can usefully supplement other obtained field data.
10. Confirm the exact locations of any permanently installed CP test coupons, CP reference electrodes, buried / submerged corrosion probes and other automated CP monitors.
11. Review previous line histories for AC and DC stray current interference.
12. Examination of Interaction Test Records and Remediation’s applied will assist in understanding the overall CP System behaviour.
13. Study CP layout alignment sheets, CP schematics and all other available design documentation.
14. Reviews of previously collected CP data can assist in focussing new field surveys on the most critical areas, and in applying the correct monitoring technologies.

**Conclusions**

Successful CP surveys, (depending on the size and complexity of the installed corrosion protection arrangements), can require considerable advance planning and knowledge sharing between asset owners, in order that all relevant data is recorded and all required route and equipment accesses are made available to complete the requested survey.

Surveys must be carefully timed, so as not to interfere with other scheduled surveys, or CP maintenance works being performed by neighbouring parties.

Similarly, all likely interference due to external sources must be understood in advance and properly accounted for, such that the true CP levels are ascertained.

An established Corrosion Forum that meets regularly and actively collaborates, greatly enhances the likelihood of meaningful CP monitoring and of cost-effectiveness CP upgrades within joint schemes, or routings.
References

(1) https://www.researchgate.net/publication/264590001_Geomagnetically_Induced_Currents_GIC_in_power_networks_as_a_source_of_electromagnetic_sounding_data


(3) http://www.aurora-service.eu/aurora-forecast/

The following additional sources of information provide useful and practical information in respect of data retrieval and planning for successful CP surveys.

1. Midstream Integrity Services, “How Drones will affect the Oil and Gas Industry, Landon Phillips, NACE Houston, Aug.2015.


Be Aware that the end of the line maybe in a hazardous area with special permit requirements. Photo. Courtesy George Ballingall – Corrpro Europe Ltd.

Think carefully about access constraints that may hinder performance of some CP survey types. Photo. Courtesy Chris Baron - Settle Land Surveys Ltd.

A Pipeline Valve Station / ESDV pit midway, having CP isolations to confirm, may be very deep. Photo. Courtesy Chris Baron - Settle Land Surveys Ltd.

Modern Survey Systems such as drones and GPS can greatly assist in CP Survey Planning. Photo. Courtesy Chris Baron - Settle Land Surveys Ltd.

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BRANCH DATES

13th June 2019
Institute of Corrosion North West Branch-50th Annual General Meeting and Golf Day
13.00 - 21.00
Venue: Heyrose Golf Club Tabley, Cheshire WA16 0HZ United Kingdom
You are welcome to bring partners, friends and colleagues, whether they are ICorr members or not to the golf day, buffet and Annual General Meeting. Teams of golfers are also welcome.

27th August 2019
Aberdeen Branch, Corrosion Awareness Day

26th September 2019
London Branch, joint meeting with SCI
18.00 - 21.00
Venue: SCI HQ, 14 Belgrave Square, London, SW1X 8PS
Topic to be confirmed.

ADDITIONAL DIARY DATES

24th June 2019
Cathodic Protection Buried ISO - Level 3 Senior Technician
IMechE Argyll Ruane, Sheffield

29th July 2019
Cathodic Protection Buried ISO - Level 2 Technician
IMechE Argyll Ruane, Sheffield

26th August 2019
Cathodic Protection Buried ISO - Level 3 Senior Technician
IMechE Argyll Ruane, Sheffield

9th September 2019
Cathodic Protection Buried ISO - Level 2 Technician
IMechE Argyll Ruane, Sheffield

9th -13th September 2019
EUROCORR 2019
Seville, Spain
Contact: http://www.eurocorr.org

2nd October 2019
Cathodic protection Concrete ISO-level 2 Technician
IMechE Argyll Ruane, Sheffield

28th October 2019
Cathodic Protection Buried ISO - Level 3 Senior Technician
IMechE Argyll Ruane, Sheffield

11th November 2019
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