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For more information contact Jonathan Phillips on 0114 273 0132 or email jonathan@squareone.co.uk
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Cover photo courtesy of Sherwin-Williams, Protective and Marine Coatings.
I would like to start by wishing a Happy New Year to all our members, and I hope that you all enjoyed the festive period.

The AGM was held in November in Birmingham after a very successful half-day technical meeting, and my thanks go to Midland Branch for once again organising these events in such a wonderful location. Hence it has now been over 12 months since John kindly passed the chain of office over to me, and the time has flown by. I am not sure if that is because of the fun I have been having or how busy we have been!

During the year the ICORR and CORREX teams have continued to work hard on our behalf in our temporary home in Barrett House, and Trevor Osborne is continuing to search for a property which we can purchase to give us a more permanent home. However in the meantime, the lease on Barrett House has been extended until July 2018.

During 2017 we ran the first “Fundamentals of Corrosion” and “Marine CP 2” courses both of which generated a lot of interest, and we will run a number of these courses again this year. Part of our development plan for 2018 is the introduction of new courses to complement our existing portfolio and to meet the market and membership needs. There are plenty of opportunities on the horizon for further increases in corrosion-related activity both in the UK and overseas, particularly in the field of training.

The Route to Chartership Initiative has been a major piece of work this past year and we are now in the process of running the first pilot. If this appeals to any of you, please contact David Mobbs via head office.

As you will see later in the magazine, ICorr, through Correx Ltd, is hosting the CEOCOR Congress in May 2018 at the Crowne Plaza in Stratford-on-Avon. The congress programme is being prepared by CEOCOR and ICorr will host the event, and have already obtained sponsorship and arranged a supporting exhibition and an accompanying person’s programme.

Individual membership of the Institute is up from last year and our Professional Members also continue to grow. Our student members have also grown, but we are seeing a decline in ‘Young Engineers’, which reflects the smaller number of graduate recruits in many of the Engineering Houses. However, during 2018 we will once again be running a Young Engineers course aimed at supporting and encouraging young graduates to flourish in the corrosion industry, and I attended the first evening session which was kindly hosted by CB&I in Paddington.

The level of volunteering within the Institute, which keeps it operating efficiently is very impressive, much of which is not publicised. However the pressure of day jobs is making volunteer work more difficult and ICorr is finding that it needs to pay for some of the tasks that need to be completed on its behalf if we are to continue to grow, as a result we have now appointed a part time Business Development Manager, David Mobbs, who started with us on 1st February.

Finally, It is with great pride that I get to visit our branches and see the strong and active organisation we are, and I hope to continue this in 2018, and thanks go to all the members who give us their time for these local events.

Sarah Vasey, ICorr President

I would like to add my good wishes to that of the President.

As has become more usual, this issue features three technical articles. Two relate to pipelines, a look at common field joint coating standards, and whether they meet the needs of the industry today, by Ian Robinson, and a discussion of the problems with can occur with corrosion resistant alloy lined pipes from Susan Jacob. The third article is an overview of epoxy curing agents. Epoxies are the workhorse of the protective coating and the article explains the effect of different curing on the resultant performance.

Over the coming months, more changes are planned to improve further the value of the magazine to members.

Remember, this is your magazine, and I look forward to hearing your views on the content. I can be contacted through the Northampton office.

Brian Goldie, Consulting Editor

Those members who have not yet applied for their complimentary badges reflecting their years of service should either telephone, or e-mail, the ICorr office. Once the request has been received, the membership records will be checked and the appropriate badge sent. When you become eligible for the next badge, it will then be sent automatically.
Welcome

WELCOME to our 173 new members and 13 Sustaining Company Members who joined the Institute in 2017.

TOGETHER WITH THE CONGRATULATIONS of the Institute to all the following members who have attained Professional Status in 2017:

**Technician**
- David A Wilson
- Keith M Wagner
- James A Ahern
- Rahul Albert Stephenson
- Chandresh Ellathuvalappil
- Nilesh Panchal
- David Kerr
- Allen McGee
- Thomas D Lamb

**Professional**
- Rajasekaran Karthikeyan
- Alistair Crichton
- Christian A Lewis
- Maria Arul Antony R
- Simeon Nnamdi Okara
- Ajay Kumar
- Ricardo Filipe
- Benjamin J Fellows
- Neil J Munro
- Asad Ali
- Stewart W Gilchrist
- Steven Brierley
- Christopher J Everett
- Amr El-Sayed Saleh Hussein
- Shan Mohan Castelino
- Adaikkalam Chidambaram
- Robert W Burrows
- Mohammad Hosseini
- Stephen F Tate
- Ankit Trivedi
- Mark A Gough
- Peter H Smithson
- Ahmed Asad
- Naveed Ul-Hassnan
- Marc Childs
- William J Smith
- Mudjat Savran
- Kamran Anjum
- Thomas Whittleton
- Azaz Mohammad Yunus Memon
- Mohammad Hussain
- Kausar Fatima Safi
- Shady Abdelsalam Abdelhamid
- Hassan
- Nikhil Paliwal
- Anthony Davidson

**Fellow**
- Edward J Boran
- Lee Wilson
- Mohnen Mazraehe
- Amit Kumar
- Jane P Lomas
- Zia H Chaudhary
- Muhammad Arsalan Khan Sherwani
- Moeen Hassan
- Robert W Flannery
- James A Seton
- Muhammad Ejaz
- Graeme Jones
- Royden de Souza
- Robert J K Wood
- William Reid
- Varghese Chakko Nettikaden

Young Engineer Programme

This year 14 students, with a cross section of the people having varying experience and from a number of locations, have been accepted for the course. The first session was held on 17 January, when Jane Lomas presented on basic corrosion.

The lecture was hosted by Sadegh Parvizi of CB&I in Paddington (the organisers are very grateful to him), and the evening chaired by George Winning of Clariant. Bill Hedges of BP opened the meeting with an introduction about the YEP programme and the benefits that the attendees will enjoy from it, meeting industry experts at the top of their field who will share their knowledge, and most importantly networking. Bill went on to explain that the course depended upon engagement and encouraged the delegates to ask questions.

The President Sarah Vasey also addressed the delegates to thank the various people involved in the programme, including the lecturers who give up their time on a voluntary basis to share their knowledge and experience. Sarah went on to say that if you look around the room you already have a wealth of experience here and involved in this programme.

Jane Lomas then presented the lecture on Corrosion which was followed by a detailed Q&A session.

The event finished with a network session in Paddington where the delegates enjoyed something to eat and drink along with valuable time to meet the other delegates in person.

It is hoped that the November meeting of London branch (the sponsoring branch) will be dedicated to the presentations of the Case Studies undertaken by the students.

Visit the ICATS website www.icats-training.org
The Institute offers training courses in two formats, residential with its partner IMechE and online with its partner Corrodere. In addition, The Corrosion Protection Association (CPA) offers the full range of ICORR Cathodic Protection of Steel in Concrete Courses in accordance with BS EN 15257 (Levels 1-3).

Courses include, Painting Inspector (Levels 1, 2 and 3), various Cathodic Protection Technician levels, Pipeline Coatings Inspector, Insulation Inspector and Fire Proofing Inspector and the new Fundamentals of Corrosion Course for Engineers.

No one can expect to become an expert in all the possible fields of corrosion control, even those of with a lifetime of experience in corrosion have tended to focus in two or three main areas. A course was therefore needed to present the basic principles that could underpin most common corrosion situations and show how the knowledge gained could be used in real life situations across a range of industries. By passing a closed book exam, the candidates could demonstrate that they had learned that fundamentals and would be able to express a professional opinion at times when there was no internet signal for back up information.

The first new ICORR Fundamentals of Corrosion (FOC) course for Engineers was run in October 2017 in Manchester and the participants were presented with an intensive four days of modules including basic corrosion reactions, types of corrosion processes, different metals, concrete, water treatment, surface preparation, paint, testing, etc, etc. The course was presented by Dr Jane Lomas, a corrosion engineer with over 40 years’ experience of marine and industrial corrosion and coating problems, who also wrote the course, and which was co-presented by Dr Les Callow, a metallurgist and corrosion engineer with over 40 years’ experience of corrosion.

Feedback received a few weeks later from the course participants tended to be “I see rust everywhere now” and “Now I can explain why our building is corroding”. It seems that there are definitely more “rust geeks” in the world now.

International Training Courses are also held through the year in various regions such as the Middle East, Asia and Oceania.

ICORR Cathodic Protection of Steel in Concrete Courses

The Coatings Working group has prepared a series of guidance documents on the following topics:
- Inspection and testing of coatings
- Organic coating application methods
- Surface Preparation methods for coating application
- Paint: a definition and generic organic coating types
- Thermal metal spray coatings
- On-site and off-site application of intumescent fire and corrosion protection coatings for steel structures

These documents are now available through the members’ area of the Institute’s web site. If you have any comments on them please send them to admin@icorr.org

Corrosion Engineering Division

The 2018 CED working day meeting will be held at the Birchwood Park Conference Centre, Warrington, on Tuesday 24 April 2018 on the subject of ‘Atmospheric Corrosion in Industrial Applications’. An information and registration leaflet is included in this issue of Corrosion Management. Exhibition space will be available for hire.

The Coatings Working group has prepared a series of guidance documents on the following topics:
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- Thermal metal spray coatings
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These documents are now available through the members’ area of the Institute’s web site. If you have any comments on them please send them to admin@icorr.org
The Branch continued its successful 2017-2018 session with a high turn-out (68 attendees) at its joint event with the Mining Institute of Scotland (MIS) and IOM3 Oil and Gas Division. Over the last few years MIS has established a strong working relationship with the Aberdeen branch and holds an annual joint technical evening that is funded alternatively.

The key topic under discussion was Corrosion under Insulation (CUI). This is a major issue for not only the oil and gas sector, but industry in general, with an estimated annual cost to the UK of £28 billion. The event started with a buffet and a poster presentation from Tianyang Lan, a MSc student from Northampton University, who presented the experimental work that he had been undertaking, assessing both physical and electrochemical techniques for measuring CUI. Two physical methods and two electrochemical methods were used in this test work, Eddy Current Testing (ECT), IR Thermography (IRT), Electrochemical Impedance Spectroscopy and Electrochemical Noise Method (ENM). The samples used to conduct the experiments were carbon steel panels at different corrosion stages, used to simulate the pipe condition, with standard maintenance organic coatings and insulation tapes representing the pipe insulation. Results have indicated that ECT/IRT could not discriminate rusting beneath a coating when it was greater than about 250microns thick however the electrochemical methods showed immense promise. Insulation of course covers all signs of corrosion.

MIS, with IOM3 Oil and Gas Division, had arranged two technical presentations. The first was given by Rebecca Allison of the Oil and Gas Technology Centre, (OGTC, a public / private initiative), who introduced the topic of CUI and the role of the OGTC in addressing the challenges of CUI. Rebecca provided an overview of new technologies being supported by the OGTC and got comprehensive feedback from the audience on these, however she highlighted that addressing CUI is not just about technology, a holistic approach including working practices, procedures, competency, human factors and data management is required.

Bill Brown and Mike Dixon of The Rope Access Company (TRAC) then built on the overview provided by Rebecca with a presentation providing results from their field and yard trials assessing the latest tools and techniques available to measure and analyse CUI, which included developments with pulsed eddy current and digital radiography. Field and yard work highlighted key issues for practitioners to be aware of.

The Oil & Gas Industry has experienced many challenges when inspecting for Corrosion under Insulation (CUI), assessing the condition of steel components under Engineered Composite Wraps and the minimum remaining wall thickness under surface scabs / blisters. The aim of their OGTC supported project is to try and determine the limitations of the available NDT methods relative to each application. TRAC plans to share the ongoing research and development overview obtained to date.

At closing, a warm vote of thanks to all the presenters was made by the new MIS President Bob Laird for their valuable contributions which were very much appreciated by all those in attendance. Next year’s joint meeting is already scheduled for 27 November 2018 at the Palm Court.

Information about all forthcoming Aberdeen branch activities can be found on the diary page of the magazine and on the Institute website, a calendar of local events of interest to corrosion professionals in the Aberdeen area and the opportunity to sign up to the branch mailing list is available at https://sites.google.com/site/icorrabz/home. Aberdeen Branch have also established their new Media Centre on LinkedIn, which can be found at https://www.linkedin.com/in/aberdeen-icorr/recent-activity/

The 2017-2018 ICorr Aberdeen Sponsors currently include: Aberdeen Foundries Ltd, Atkins, CAN Offshore Ltd, CORRPRO Companies Europe Ltd, Cosasco, Deepwater, ICR, IMG Composites, IndCorr, LR, North East Corrosion Engineers, Oceaneering International Services, Permasense, Pipeline Technique Ltd, Plant Integrity Management, Spencer Coatings, Rosen, R&R Corrosion Ltd, Total E&P and TRAC.
Institute News

The 29th London Branch Lunch, held at The Royal Overseas League in early December, was another huge success with 177 people attending the event in Mayfair London.

Guests started to arrive at 11.30 for a pre-lunch drink and were seated by 12.30 for the first of two acts by The Sirens a group of three singing performers, which was really well received and set the scene for the afternoon. The meal was yet again excellent and congratulations to the ROSL who never disappoint. After the lunch the Chair of London Branch thanked the luncheon organising committee ad the branch committee, who continue to drive the Institute in London forward.

The President then addressed the guests to a rapturous applause once again thanking everyone for their support and explaining that the Institute has exciting plans that will start in Q1 2018.

After the raffle, two guests were honoured with a small gift in recognition of them receiving the Tallow Chandlers Award for their work in materials and corrosion, a tremendous achievement by Charlotte Vie in 2016 and Simon Bowcock in 2017.

The timing for the event this year was slightly different allowing guests to socialise and network at the ROSL until 7.00pm which appeared to be extremely popular with lots of notes being taken and exchanging of business cards.

Thanks go again to all those that assisted in the organisation of the event and we look forward to another exciting event in December 2018.

London Branch

The second presentation of the 17/18 season was a joint meeting with TWI, and James Hesketh of the National Physical Laboratory gave a presentation on the Influence of H₂S on the Pit to Crack Transition in Sour Testing of Corrosion Resistant Alloys.

James highlighted that stable pitting is a precursor to sulphide stress corrosion cracking (SSCC), which is one of the main causes of failure of stainless steel pipelines used in sour Oil and Gas production. Despite this, the underlying mechanism governing the growth of such pits is poorly understood, and hence materials selection for sour service is dependent upon costly and time consuming environmental exposure and SSCC test programmes.

In the study at NPL, the role of hydrogen sulphide (H₂S) in pit propagation was investigated as a first step towards the development of accelerated test methods for SSCC resistance. Novel electrochemical techniques were employed to determine the relationship between bulk solution chemistry and the critical pit chemistry required to induce stable pitting in sour environments. James stressed that electrochemical measurements are correlated with results obtained from standard SSCC tests and are rationalised in terms of the balance between H₂S diffusion through the pit mouth, H₂S consumption within the pit and the role of the external cathode.

He also explained that there was a systematic decrease in pit size with increasing H₂S concentration. Also that a greater peak current was measured at higher H₂S concentrations and repassivation was slower.

The talk introduced and explained the benefits of stress monitoring in pipeline integrity management. It is the only inspection technique that can simultaneously map the lateral position and depth of cover of a pipeline whilst providing comprehensive defect detection. Several case studies were discussed to illustrate the advantages of this the technique, also known as Stress Concentration Tomography, over traditional inspection methods. The technique is able to assess condition of buried pipelines remotely and is not dependent on the type of defect, size of pipe, construction configuration or operating condition, and can save a considerable amount of time, effort and budget while providing an accurate 3 dimensional mapping of a pipe and surrounding objects. The technique can also identify location of casings and wrinkle bends, information becoming required by the regulatory authorities.
Bill left Bolton School in 1940, when he was 18, and went to work at the Chemical Defence Research Establishment in St Helens, synthesising mustard gas and other poisonous gases.

He worked there until 1941, when he decided to volunteer to join the RAF. After active service, he was demobbed in June 1946, and started as a student at Manchester University in 1946. He studied there until 1949, when he graduated and began his career at W & J Leigh & Co, rising to the position of Chief Chemist – a position that he held with distinction until he took early retirement in 1984.

Bill was renowned for his encyclopaedic knowledge of anything connected with paint technology, and his approachability and willingness to share this knowledge with any of his staff, from laboratory managers, right down to the most junior technician.

He was an active supporter of the Institute of Corrosion and for two years was Chairman of the North-West Branch. In addition, he was a 50-year life member of OCCA.

Bill Holden will be fondly remembered as a great leader, mentor and most importantly an absolute gentleman.

Compiled by Malcolm Morris and Bill Cox.

Obituary, William Desmond (Bill) Holden - August 1922-November 2017
Spencer begins Forth Road Bridge repairs

Spencer Group has begun preliminary work on repairs to the truss ends on the Forth Road Bridge, following a fracture that closed the bridge for three weeks for emergency repairs. Transport Scotland has contracted Spencer to replace seven truss ends that connect the bridge deck to the tower following their failure in December 2015.

A temporary solution was put in place by Amey at the time but permanent works are now under way. Amey has a maintenance contract with Transport Scotland for the Forth Road Bridge, and their emergency works made the bridge safe to re-open. It replaced the existing truss ends on the northeast span with a new sliding bearing, and Spencer is now responsible for the remaining truss ends on the rest of the bridge, where the obsolete sections must be cut out and replaced with a sliding bearing system.

The truss end link replacement works require a series of complex works to be delivered to a part of the Forth Road Bridge that has limited accessibility and was never designed with replacement in mind. The tower cells adjacent to the location of the replacement works require strengthening to take the combined 14-tonne weight of the support bracket and new sliding bearing, which need to be barged out and hoisted up into their final position.

As part of the works, Spencer will also install modifications that will make future works on the bearings easier. This includes installation of new access stairs and permanent access platforms to allow easy maintenance all year round without the need to erect temporary steelwork. This will make future maintenance safer, and allow it to be carried out with little disruption to the normal operation of the bridge.

Latest Literature

United Kingdom: Paints and Varnishes - Market Report - Analysis and Forecast to 2025

This new report provides an in-depth analysis of the market for Paints and Varnishes in the United Kingdom. It presents the latest data on the market size and volume, domestic production, exports and imports, price dynamics and turnover in the industry. The report shows the sales data, allowing the identification of the key drivers and restraints. It contains a strategic analysis of key factors influencing the market, and forecasts illustrate how the market will be transformed in the medium term. Profiles of the leading companies and brands are also included.

A similar market report is available covering the EU: Paints and Varnishes.

Full details can be found at, https://www.researchandmarkets.com/research/3nv7p4/united_kingdom

New Book on Coatings for Marine Vessels

CorrCompilation: Coatings for Marine Vessels, is the latest book by coatings and corrosion expert Todd Byrnes. It features case studies and an insight into the most recent developments in marine vessel coatings, ballast tank linings and antifouling technologies. The book also addresses recent trends in the marine coatings industry, such as new legislation relating to safety and environmental considerations, new-generation technologies in surface linings and design challenges faced by ship builders and asset owners. It provides a useful guide for coating specifiers, paint applicators, shipyard and mobile platform owners, coating inspectors, maintenance engineers, and naval and commercial vessel owners, and is available in paperback or as an e-book in the NACE Store, (https://store.nace.org) price $130 or for NACE members, $87.50.

Inspection Instruments for the Pipeline Coatings Industry - Volume 3: Verifying the Quality of Coating Installation - Post-Application

The last of three volumes, this e-Book provides information on the proper use of test instruments for verifying the quality of the application of protective coatings after the installation process is complete. It is applicable to new pipe in the shop, field splices (girth weld areas), existing pipe in the field, and painted steel in general. It can be downloaded free from https://ktuniversity.com, as can copies of volumes 1 and 2.

Electrochemical Methods in Corrosion Research, Robinson College Cambridge, 22 – 27 July 2018

A Call for Papers has been issued for this residential, single-session conference. All aspects of corrosion research with an electrochemical component will be considered, and topics of particular interest include, electrochemical methods (e.g. impedance, noise, polarisation, high temperature), scanning and microprobe techniques (e.g. SECM, SVP, LEIS, AFM-based), and the areas of environmentally assisted cracking and hydrogen detection, coatings, energy materials (e.g. oil and gas, nuclear, non-conventional), cathodic protection, and inhibition and water chemistry.

Abstract submission deadline 13th April 2018, and conference registration deadline is 4th June 2018.

Further details can be found at http://emcrconference.org/
Engineering Tools for corrosion: Design and Diagnosis (EFC 68), by Luciano Lazzari

This is the latest volume in the European Federation of corrosion series published by Woodhead Publishing. It presents a rational approach to the corrosion prediction and evaluation dilemma, illustrates new models and algorithms for quantitative estimation of corrosion related factors and parameters, and includes the design and interpretation of accelerated corrosion tests.

The book includes discussions of the estimation of main corrosion parameters for corrosion rate, electrochemical constraints, thresholds limits and initiation time. The algorithms proposed are the conjugation of theory and engineering practice resulting from research and professional activities carried out by the author for almost four decades.


EFC-Workshop 2018: High Temperature Corrosion under Complex Conditions, Deposits and Salts: Towards Greener Energy

A Call for Papers has been announced for this event which will be held on 26 – 28 September 2018, at DECHHEMA-Haus, Frankfurt am Main, Germany. Experts and young scientists with research interests in the high temperature corrosion of metallic materials and coatings in existing and emerging applications for greener energy conversion and transportation are invited to submit their contribution at www.dechema.de/efcws2018. The deadline deadline for contributions is 13 April 2018.

The topics for oral and poster presentations may address but are not limited to experimental evaluation of corrosion kinetics, mechanistic understanding and modelling of corrosion processes and related degradation of material microstructures, using advanced analytical techniques for elucidating the complex corrosion phenomena including those induced by deposits and salts.

Further information can be obtained from, Dr. Rolf Lenke, e-mail: lenke@dechema.de

Advances in coatings Technology, ACT’18

The Institute for Engineering of Polymer Materials & Dyes, Paint & Plastics Department, Gliwice, Poland invites scientists to present a paper at the 13th International Scientific – Technical Conference for paints to be held on 13 – 15 November 2018 at the Expo Silesia Exhibition Centre in Sosnowiec, Poland.

The main topics covered at the Conference, include the latest developments in raw materials for coatings, advanced technologies and applications, analysis and testing of coatings, equipment, ecology, legislation and market trends.

New restrictions on diisocyanates due to their potential negative health effects

The European Chemicals Agency’s Committee for Risk Assessment (RAC) and the Committee for Socio-Economic Analysis (SEAC) voted to approve restrictions on diisocyanates in workplace settings based on a proposal submitted by Germany. The goal of the restrictions is to reduce the incidence of asthma attacks stemming from exposure to these compounds.

The regulations, which are not official until finalised by the EC, would limit the use of diisocyanates to applications in which they comprise no more than 0.1 percent of a product by weight, and call for more comprehensive training for workers who will be in contact with the substances. The 0.1 percent limit includes exemptions for situations in which there is very low potential for exposure or no relevant risk of occupational asthma.

Diisocyanates including methylene diphenyl diisocyanate (MDI) and toluene diisocyanate (TDI) are combined with polyols to create polyurethanes and polyureas, commonly used in paints and coatings. According to the ECHA, the 0.1 percent limit generalises what had been the most restrictive limit on certain isocyanate compounds, applying that limit to all isocyanates.

Under the proposed regulations, employers whose business involves diisocyanates would be required to establish and regularly update a set of teaching materials to inform employees about the risks of exposure.

According to the National Institute for Occupational Safety and Health, isocyanates can cause asthma as well as irritation to the skin and mucous membranes. Exposure, even just to the skin, can cause sensitization such that a worker can suffer a severe asthma attack upon re-exposure at a later point.

RAC and SEAC are also considering risks to health from other chemicals, including some used in coatings and surface treatments, such as chromium (VI) substances.
Standards Update

The following is a list of standards relative to our industry published by ISO and CEN (including joint ISO standards) during November and December.

ISO

The following draft International Standards have been submitted to the ISO member bodies for formal approval.


ISO/FDIS 19097-1 Accelerated life test method of mixed metal oxide anodes for cathodic protection — Part 1: Application in concrete

ISO/FDIS 19097-2 Accelerated life test method of mixed metal oxide anodes for cathodic protection — Part 2: Application in soils and natural waters

Standards issued in November and December include,


ISO 3183:2012/Amd 1:2017 Petroleum and natural gas industries — Steel pipe for pipeline transportation systems — Amendment 1

ISO 2819:2017 Metallic coatings on metallic substrates — Electrodeposited and chemically deposited coatings — Review of methods available for testing adhesion

ISO 11130:2017 Corrosion of metals and alloys — Alternate immersion test in salt solution


This standard specifies general methods for determining the resistance of an individual-layer or multi-layer system of coating materials to the effects of liquids, other than water, or paste-like products.


This specifies spotting methods for determining the resistance of an individual-layer or multi-layer system of coating materials to the effects of liquids or paste-like products. These methods enable the testers to determine the effects of the test substance on the coating and, if necessary, to assess the damage to the substrate.


ISO 27850:2017 Metallic and other inorganic coatings — Requirements for the designation of metallic and inorganic coatings

ISO 9177:2017 Metallic and other inorganic coatings — Phosphate conversion coating of metals

ISO 16809:2017 Non-destructive testing — Ultrasonic thickness measurement

CEN

EN 353-1:2014+A1:2017 Personal fall protection equipment - Guided type fall arresters including an anchor line - Part 1: Guided type fall arresters including a rigid anchor line

This European Standard specifies the requirements, test methods, marking, information supplied by the manufacturer and packaging for guided type fall arresters including a rigid anchor line. Guided type fall arresters including a rigid anchor line conforming to this European Standard are components of one of the fall arrest systems covered by EN 363. This European Standard applies to rigid anchor lines which are intended to be installed vertically and/or with a combination of forward-leaning angle and/or sideways leaning angle. Multi-user applications, i.e. rigid anchor lines that allow more than one user to be attached at any one time, are not addressed in this document.


The standard specifies techniques for the manual ultrasonic testing of fusion-welded joints in metallic materials of thickness ≥8 mm which exhibit low ultrasonic attenuation at object temperatures from 0 °C to 60 °C. It is primarily intended for use on full penetration welded joints where both the welded and parent material are ferritic. Where material-dependent ultrasonic values are specified in ISO 17640:2017, they are based on steels having an ultrasonic sound velocity of (5 920 ± 50) m/s for longitudinal waves and (3 255 ± 30) m/s for transverse waves. It specifies four testing levels, each corresponding to a different probability of detection of imperfections.


The standard specifies a destructive method for determination of the dry film thickness, in which damage to the coat caused in a definite manner is evaluated microscopically. The method is suitable for almost all coat-substrate combinations and also allows determination of the single film thicknesses of coating systems.

The Society for Protective Coatings (SSPC)

SSPC has announced the revision of standard SSPC-PA 7, Applying Thin Film Coatings to Concrete.

The 2017 revision clarifies that “thin film” refers to coatings with specified dry film thicknesses under 500 microns, and notes the requirements that the contractor needs to verify to ensure the surface preparation of the substrate meets contract requirements prior to coating application. Prior to placement, coatings must be cured in alignment with manufacturer recommendations, and that any touch-up must be done in accordance with either project requirements or the originally specified coating system.

SSPC-PA 7 is intended to be used by both owners and specifiers to supplement product application requirements.
Innovative Products

The CEOCOR 2018 CONGRESS, administered by the Institute and CORREX Ltd, will be held from May 15th until May 18th 2018, at the Crowne Plaza, Stratford on Avon.

The conference, and associated exhibition, will cover recent research and experiences on corrosion and protection of pipes and pipeline systems in the field of drinking water, waste water, gas and oil. This is the first time that the CEOCOR Congress has ever been held in the UK, and everyone who is a specialist in internal or external corrosion, corrosion protection or integrity management, CP, coatings, inspection and materials for buried pipelines should take this chance to attend this 'hidden gem' of the corrosion calendar.

Registration is now open and full details and a registration form can be found on the CEOCOR 2018 website (www.ceocor2018.com). Download the registration form and submit to Correx Ltd to reserve your place, and as it appears that the Congress will be fully booked, if you intend to participate at what will be the biggest and best buried pipeline corrosion and protection meeting in Europe this year, you need to book now.

Bookings are now also being taken at the Crowne Plaza hotel (you need to book directly, and mention CEOCOR to obtain the discount). A very limited number of rooms are held for 14 May for people travelling long distances, and the remainder of rooms, held from 15 to 17 May, must be reserved by 10 April, otherwise they will be released back to the hotel.

The Congress presentations are managed directly by CEOCOR, and many proposed presentations have already been received and are being reviewed by the senior CEOCOR specialists. The final deadline for submission of a paper is 20th February 2018, so if you have something of high quality, preferably innovative and non-commercial, to present, be quick and submit.

There are now 21 Sponsors, Exhibitors and Supporters booked to participate. The lead Sponsor and exhibitor is National Grid, the UK’s gas transmission network operator. Other key Sponsors include Cathodic Protection Co. Ltd, CTS Europe Ltd, 3C, MetriCorr and Rosen Group. Other important Sponsors and Exhibitors are from the cathodic protection specialist areas covering engineering services, materials and instrumentation along with testing specialist and pipeline coating suppliers. There are (at time of going to press) only 2 available spaces left. If you wish to Sponsor, preference will be given to those wishing to be Gold or Silver Sponsors, so be quick. Lunch Sponsorships are also available. Full details again are on the web site.

The full program will be released in March when the Congress papers have been finalised. On May 15 the Congress starts with CEOCOR Work Groups and there are more on the 18th. May 16 and 17 are devoted to the full Congress technical presentations along with the technical exhibition. Sponsors have supported the Congress Dinner and the BBQ with Jazz evening (16th & 17th), and there is a full partner’s program. See the web site.

This will be one of the best technical meetings that you have ever attended. If you have never participated before in CEOCOR be prepared to be surprised by the high quality of presentations and discussions and the open exchange of information, along with the friendships that can be built with technical specialists of high competence levels from Europe and elsewhere. Make this a meeting where the UK is strongly represented.

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Innovative Products

Hemgel reduces cargo hold maintenance costs by launching new Hempadur Ultra-Strength Fibre 47510

Global coatings manufacturer Hempel has launched a new cargo hold coating – Hempadur Ultra-Strength Fibre 47510, which, according to Davide Ippolito, Group Project Manager, Marine, Hempel A/S, offers customers an outstanding return on investment by delivering up to 40 per cent reduction in cargo holds maintenance costs (compared to a standard epoxy coating for cargo holds in a Panamax bulk carrier).

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Technical Article

Specification and selection of Field Joint Coatings for buried pipelines - do current standards help or hinder the decision maker?

Ian Robinson, 3M, UK

Pipeline operators and coatings specifiers can often be faced with an almost bewildering array of products/technologies when selecting the most appropriate solution for their field joint coating needs. Before looking at the role that current standards might play in the decision making process, it is perhaps useful to explore the fundamental purpose(s) of a field joint coating and to consider some related requirements which can all too easily be over-looked within the decision making process.

Whilst a field joint coating may need to exhibit a considerable number of different performance attributes - for example, adhesion, damage resistance, impermeability towards oxygen and water/electrolytes, temperature/chemical resistance and compatibility with the main line coating - an appropriate suite of performance attributes is simply a way of ensuring that the desired long term protection can be provided within the operating environment over the lifetime of the pipeline. The over-arching requirement is that the field joint coating, once installed, should provide reliable corrosion protection for the design life of the pipeline. The key phrase here is “once installed”, in that for many projects the field joint coating may have to be installed in widely differing topographic and climatic regions, and/or be subject to seasonal climatic variations, during the construction phase of the project. Clearly these factors must be taken into consideration when selecting a field joint coating system, and that performance attributes in isolation cannot provide an entirely reliable basis for selection.

An ideology increasingly agreed to by many suppliers within the industry, is that the field joint coating should replicate as closely as possible the factory applied parent coating, thus providing equivalent performance from both the factory and field applied systems. This may seem a plausible argument, but does it really stand up to close scrutiny? If it is accepted that the purpose of the installed field joint coating is to afford reliable corrosion protection for the design life of the pipeline, then there is no logical reason as to why the factory applied main-line coating and the field applied coating must be the same. To understand this it is sufficient to consider the external influences the factory applied coating may potentially be exposed to, prior to and during the construction phase of the project, none of which the field joint coating will ever be subjected to, for example, mechanical handling and storage at the pipe coating plant, mechanical handling and transportation to the construction site, mechanical handling and welding at the construction site, to name just a few. In fact, it has been reported that the factory coated pipe could be moved as much as 39 times from leaving the factory until the trenches have been filled at the construction site. Embodying performance characteristics within the field joint coating to accommodate these factors would essentially be an unnecessary over-design which ultimately does not add value, and may preclude the use of alternative systems potentially more suited to the specifics of the pipeline construction site whilst still being capable of delivering the desired long term performance outcome(s).

From the foregoing comments it is perhaps not unreasonable to conclude that a “universal” field joint coating is probably very unlikely to exist, so how can appropriately informed decisions be made? Firstly, the practicalities of application at the construction site must be considered. Pipelines may pass through regions of widely differing climate and topography and construction may have to take place during extremes of summer and winter conditions. This immediately places considerable constraints on the field jointing and may go some way to narrowing down any list of candidate solutions. Secondly, the ease or simplicity of installation of candidate systems needs to be considered - will a specialist field joint coating contractor be employed or will the selected system need to be sufficiently forgiving to be capable of being reliably installed by a local direct labour force? Finally, the anticipated in-service operational conditions must obviously be carefully considered. As a further example, consider the requirements that are called out for the impact resistance of liquid epoxy and PU coatings (Codes 4A/4B) we see a cathodic dis-bonding requirement of ≤ 15mm at maximum operating temperature for liquid epoxy coatings but a requirement of ≤ 20mm for liquid PU coatings. If we look at flame sprayed polyethylene (PE) and polypropylene (PP), or PE/PP tapes or sheets, utilized in conjunction with liquid or fusion bonded epoxy primers (Codes 5A/5B/5D/5E), a dis-bonding requirement of ≤ 10mm is called out. However, in the case of single or dual layer fusion bonded epoxy systems (Cases 3A/3B), no dis-bonding requirement at maximum operating temperature is stipulated at all, just a requirement of ≤ 15mm at 65°C. Systems satisfying the above performance criteria could therefore all justifiably be claimed to be in compliance with the standard, yet clearly could exhibit very different levels of performance.

ISO 21809-3: 2016

- Specifies requirements for field joint coating of seamless or welded steel pipes for buried and submerged sections of pipeline transportation systems used in the petroleum, petrochemical and natural gas industries.
- Classifies field joint coatings into 8 generic groups (“Codes”), with up to 5 sub-groups within each.
- Specifies minimum performance requirements for each group/sub-group.

Interestingly, the stated minimum requirements are different for virtually every Code. For example, in the case of liquid epoxy and liquid PU coatings (Codes 4A/4B) we see a cathodic dis-bonding requirement of ≤ 15mm at maximum operating temperature for liquid epoxy coatings but a requirement of ≤ 20mm for liquid PU coatings. If we look at flame sprayed polyethylene (PE) and polypropylene (PP), or PE/PP tapes or sheets, utilized in conjunction with liquid or fusion bonded epoxy primers (Codes 5A/5B/5D/5E), a dis-bonding requirement of ≤ 10mm is called out. However, in the case of single or dual layer fusion bonded epoxy systems (Cases 3A/3B), no dis-bonding requirement at maximum operating temperature is stipulated at all, just a requirement of ≤ 15mm at 65°C. Systems satisfying the above performance criteria could therefore all justifiably be claimed to be in compliance with the standard, yet clearly could exhibit very different levels of performance.

As a further example, consider the requirements that are called out for the impact resistance of liquid epoxy and PU coatings (Codes 4A/4B): ≥ 3 Joules/mm for liquid epoxy but ≥ 5 Joules/mm for liquid PU. Assuming the minimum acceptable values pertain, an epoxy system applied at 0.5mm thickness would afford an impact resistance of 1.5 Joules, whereas a PU system applied at 1.5mm thickness would afford an impact resistance of 7.5 Joules. It seems illogical that one system could provide 5x the impact strength of the other yet both systems could be claimed to be in compliance with the standard.

Whilst being admirable in terms of capturing the plethora of product types currently available in the market, as can
be seen from the foregoing examples the standard does not readily lend itself to making meaningful comparisons across different product categories - rather it tends to reflect the inherent or anticipated performance characteristics of generic product groups - thus providing little assistance in selecting a system that will be suited to the project specific requirements. Fundamentally, compliance with the standard, for any class of coating, does not provide confirmation that the system will actually fulfill the specific requirements of the project. As just one example, a liquid epoxy coating conforming to ISO 21809-3 (Code 4A), with a maximum operating temperature of 60°C, could provide a very good solution for a given project, yet it could equally provide an entirely inappropriate outcome.

CSA Z245.30-14 (Canadian Standards Association)

- Specifies requirements for field-applied external coatings for steel pipeline systems intended primarily for buried or submerged service in oil or gas pipeline systems.
- Covers 7 classes of coating system (FC1 – FC7), primarily fusion bonded epoxy, plus tapes and heat shrinkable systems.
- Specifies minimum performance requirements for each class of coating.

In many respects this standard exhibits similarities with the general format and style of ISO 21809-3, albeit with a reduced number of product categories. Whilst there is a consistency of requirements across generically similar product classes – for example in the case of the three classes of fusion bonded epoxy (FBE) coatings – once again there are widely differing minimum requirements called out for generically different systems such as FBE coatings, tapes, heat shrinkable systems and viscoelastic materials. As an example, the stipulated cathodic dis-bonding requirement for all three classes of FBE coatings (“standard”, “high temperature” and “dual layer”) is ≤ 8.5mm at 20°C, whereas the requirement is ≤ 12mm for tapes and heat shrinkable systems, and ≤ 20mm for viscoelastic materials. At maximum design (operating) temperature a requirement of ≤ 10mm is called out for all three FBE systems, yet no requirement is stipulated for tapes, heat shrinkable systems and viscoelastic materials other than “meets manufacturer’s specification”.

As is the case with ISO 21809-3, the standard documents some useful minimum requirements for a number of classes of field joint coating but doesn’t readily lend itself to drawing comparisons across generically different classes of material.

EN 12068

- Specifies the functional requirements and test methods for external organic coatings based on tapes or shrinkable materials to be used for corrosion protection of buried and immersed steel pipelines in conjunction with cathodic protection.
- Defines the functional performance requirements for three classes of mechanical resistance – low (Class A), medium (Class B) and high (Class C) – and three classes of maximum operating temperature – up to 30°C (Class 30), up to 50°C (Class 50) and > 50°C (Class HT).
- Classifies coating systems according to both mechanical resistance and maximum continuous operating temperature, for example EN 12068-B 30, EN 12068-C 50, EN 12068-C 60 (HT) etc.

Unlike the two aforementioned standards, EN 12068 clearly defines the minimum performance requirements which must be satisfied in order for a coating system to attain a particular classification. Thus for any classification the minimum functional performance requirements are constant, irrespective of the coating type, thereby providing a means of directly comparing one coating system against another with respect to defined performance criteria.
By way of example, consider a selection of the functional performance requirements called out for mechanical resistance Classes A, B and C respectively, assuming a Class 50 operating temperature classification:

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Temp.</th>
<th>Mechanical Resistance Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact resistance (Joules)</td>
<td>23</td>
<td>≥ 4  ≥ 8  ≥ 15</td>
</tr>
<tr>
<td>Indentation resistance (N/mm²)</td>
<td>50</td>
<td>0.1  1.0  10.0</td>
</tr>
<tr>
<td>Peel strength to pipe (N/mm)</td>
<td>23</td>
<td>≥ 0.40 ≥ 0.40 ≥ 0.50</td>
</tr>
<tr>
<td>Peel strength to factory coating (N/mm)</td>
<td>50</td>
<td>≥ 0.04 ≥ 0.04 ≥ 0.05</td>
</tr>
<tr>
<td>Specific electrical insulation resistance (Ω.m²)</td>
<td>23</td>
<td>≥ 10⁴  ≥ 10⁴  ≥ 10⁴</td>
</tr>
</tbody>
</table>

Whilst it is not the purpose of this article to review the appropriateness of the acceptance criteria cited in the standard, this style of classification would appear most helpful to any decision maker tasked with selecting the right field joint coating for their project. If the requisite performance levels for the project are defined, then the decision maker is able to potentially consider multiple technologies or products meeting those requirements and make an informed decision based on other pertinent criteria, such as ease/speed of installation and cost. It should be noted, however, that the scope of EN 12068 is limited to tapes and heat shrinkable materials. It therefore excludes a number of other highly useful technologies - for example fusion bonded epoxy, two component liquid applied coatings and flame sprayed poly-olefins.

**Conclusions**

The “ultimate” or “universal” field joint coating therefore does not exist, but there are many varied and well proven technologies currently available, all of which have their strengths and weaknesses. However, specifying or selecting the most appropriate solution for any given project is not necessarily straightforward. In such situations reference to standards is often the first port of call, but in the case of field joint coatings this presents some challenges. ISO 21809-3: 2016 and CSA Z245.30-14 are both commonly quoted in the industry but suffer from the same shortcomings, in that they specify minimum performance requirements for a wide variety of generic classes of coating system yet the requirements are quite different from one class to the next. Thus, as previously noted, compliance with the requirements of the standard provides no confirmation that the system in question will fulfill the specific needs of the project. Rather, that will depend upon whether an appropriate generic system has been specified in the first instance. EN 12068 adopts (in the author’s opinion) a more logical approach, defining mechanical classes of performance which are universal and not specific to any generic technology, thereby enabling multiple technologies to be assessed against a common set of requirements. The down-side of the standard is that its scope is confined to tapes and heat shrinkable materials, so it cannot be considered universally applicable. The ideal industry standard would therefore seem to be one which mirrors the approach utilized in EN 12068, combined with the breadth of scope associated with ISO 21809-3.

**References**

An investigation into the wrinkling phenomenon on CRA lined pipelines and its impact on pipeline integrity

Susan Jacob, Asset Integrity Engineer - Can Offshore Ltd.

In Oil and Gas production, there are two main phases of transporting the fluids, both of which use metallic tubular products. Smaller diameter pipes are generally used for wells and flowlines, and larger diameter pipes for onward transport to oil and gas processing terminals. The material selected for the pipework depends on the reservoir fluid composition and expected LOF – Life of Field, to ensure they can withstand both the external and internal environments, and to enable the safe transportation of fluids over a long-term operating period. Subsea pipelines must be protected both internally and externally from corrosion hazards.

Externally the pipe material, (most commonly pipe grade Carbon Steel) is exposed along its length, to a fairly constant electrolyte – seawater, which can be protected externally by a combination of Coatings, Weight Coatings and Cathodic Protection, (normally of Sacrificial Type). These methods are well proven to provide long-term corrosion protection. However, internally the situation is much more complex and far less predictable, and mitigation methods especially when using carbon steel may change throughout Life of Field, as the reservoir characteristics, operating parameters and pipeline usage all alter.

**Internal Corrosion Assessment**

Most operators have bespoke risk analysis / corrosion rate calculation tools that are designed to capture their own environmental and operating parameters that could affect corrosion rates for carbon steels.

Proprietary software is also available but all of these products have limitations, and cannot capture all variations of conditions, some of which may occur in service, at short notice. These models are most commonly used in combination with varying levels of chemical mitigation, to arrive at a final predicted corrosion result / rate, which is then applied to determine final installation pipe thickness / pipe schedule and Corrosion Allowance (CA). Corrosion rates with (assumed) corrosion inhibition in place generally have a much lower corrosion rate in comparison to no inhibition cases.

In order to predict the time to failure in the event of localised wall loss, two approaches might typically be considered. The first approach is somewhat optimistic, whereby the pipeline is considered to have corrosion inhibition 95% of the time, while 5% of the time it has no chemical inhibition at all, whilst the second is commonly a very pessimistic approach, where the pipeline has no available corrosion inhibition or injection possibilities.

A range of intermediate assumptions on inhibition levels and process variants can of course be applied and the individual and / or combined effects of model inputs charted to provide a fuller picture, depending on time and resources available to the Oil / Gas operator. Chemical efficiency and partitioning, (distribution to production phases – condensate, gas, oil, produced water etc) can also be independently assessed, but such detailed analysis is not always possible.

It should perhaps be noted at this stage that there are now many far smaller operators in the North Sea, compared to the giants of the past, and they seek simple and reliable solutions to these internal corrosion and treatment issues.

Corrosion Resistant Alloy (CRA) lined carbon steel pipes are becoming more commonly used in the offshore oil and gas industry for High Pressure / High Temperature export lines, mainly because of their ability to transport corrosive hydrocarbon fluids without losing their integrity. This article focuses on their use and the potential causes of CRA wrinkling experienced in a North Sea Export Pipeline, subsequent to the wrinkling growth, detection and long-term Integrity impacts. It highlights many of the issues and considerations in the use of such materials for internal corrosion protection.

**The use of CRAs in the UK oil and gas industry as a mitigation alternative**

As a corrosion mitigation strategy, if CRA lined pipes are not used, then a continuously injected cocktail of chemicals might otherwise be required to prevent corrosion from produced gases CO₂ and H₂S, bacterial contamination, and scale blockages from mixing of injected and produced waters. Additionally, it is not uncommon for pipelines to experience scale blockages from mixing of injected and produced waters, unless prepared for and chemically treated in advance, can cause untold internal damage and potentially lead to pipeline down rating and reduced operating capacity. Hence the attractiveness of the use of CRAs, as a primary internal mitigation to ensure Integrity is maintained.

The higher cost of using CRAs, can be partially offset by using a thinner CRA cladding, as opposed to the use of CRA material throughout. The CRA thickness is normally similar to the typical Corrosion Allowance (CA) for a carbon steel pipeline, i.e between 3-6mm. Mechanically-applied CRAs are generally preferred over metallurgical clad lines, due to their more cost-effective nature and the simple hydroforming process where the liner is hydraulically expanded to fit into the carbon steel pipe.

**Advantages and disadvantages of thin walled CRAs for pipelines**

The improved corrosion and erosion resistance of CRAs, (if of appropriate material and thickness for internal flow condition), is an undoubted advantage to Oil and Gas Operators, provided that this material is not penetrated when in-service to create a galvanic couple (as discussed below). The use of thin-walled CRAs is usually considerably more cost effective than use of solid CRA.

However from a review of available literature, it is also obvious that there can be other mechanical disadvantages with both Pipe-in-Pipe systems and CRA lined systems, from design through to installation, most particularly with mechanically bonded CRA liners and the risk of wrinkling occurring to them at pipeline.

Although mechanically lined pipes can endure operational loads such as bending, tension and internal or external pressure, there will be a point in the plastic bending where the liner will come away from the carbon steel pipe. This causes the liner to buckle in the form of circumferential deformations or wrinkles. These wrinkles can be seen particularly in lined pipes that have undergone reeling installations, and more recently with snake-lay type installations.

The snake-lay installation method maybe used to reduce the effects of lateral buckling, but it could be argued that there has been insufficient consideration/procedural development to date, to help overcome these negative effects that can impact on the long-term life of the CRA liners.
Additional risks of internal scaling and galvanic corrosion

For a pipeline that sees unprocessed production fluids from various wells there is a high probability for scale build up. The common types of scale in offshore reservoirs are carbonates or sulphates of calcium, barium or strontium. In some circumstances, oxide and sulphide salts of iron, lead and zinc may also form scale. Hence in the most optimistic approach (i.e. 95% corrosion and scale inhibition availability), it is necessary to reduce scale build up and maintain a low general corrosion and under-deposit rate.

The additional possibility of galvanic corrosion must also be considered, in the event of areas of wall loss / penetration to a CRA liner, due to aggressive scale clearing, as commonly the carbon steel pipe and the CRA liner are mechanically bonded and in electrical contact.

In the event of a breach of the CRA liner, the carbon steel will be exposed to the conductive process electrolyte and become the anode and the CRA liner the cathode. Increased general corrosion, and most dangerously pipe wall pitting, could potentially occur on the anode in comparison with the CRA cathode. This is due to the theoretical dissolution of iron occurring at the anode, \( \text{Fe} = \text{Fe}^{2+} + 2e^- \), balanced by a cathodic reaction which in neutral to alkaline liquids involves reduction of dissolved oxygen, \( \text{O}_2 + 2\text{H}_2\text{O} + 4e^- = 4\text{OH}^- \).

In Francis on Galvanic Corrosion [1], there is a relevant discussion on the effect of coupling two metals with different electrode potentials in sweet produced fluids, which has been investigated by various researchers. One of the examples studied was the coupling between carbon steel as anode, and CRAs as cathode in a 5% sodium chloride (NaCl) medium with 8.2 MPa \( \text{CO}_2 \) at 150°C for a test duration of 30 days. The corrosion rate of the coupled carbon steel was however in this instance, not much higher than the corrosion rate of uncoupled carbon...
S-Lay Method mostly used for Larger Diameter Pipelines. The "S" refers to the shape the pipe forms between the vessel and the seabed as it is laid. Courtesy of Subsea7.
steel. Setting up a cathode-to-anode area at a ratio of 4:1 did not raise the corrosion rates to any significant level in this case.

Relating to the particular circumstances of this example, a small area of carbon steel (anode) being exposed due to impingement of the CRA liner (cathode) within the pipeline would not significantly affect the corrosion rate and can hence could be considered as low risk. However, every internally lined pipeline is best tested, using its own individual operating parameters and water chemistry for such a scenario, as one size should never be assumed to fit all.

The effect of flow rate on galvanic corrosion was also considered by Frances [1] in which investigations comparing corrosion rates in flow and static conditions showed galvanic corrosion to be higher in static conditions than in flow conditions, which is a very important consideration.

**Wrinkling assessment and integrity significance**

Yuan and Kyriakides [2] illustrated the life span of a wrinkle leading to a failure scenario through FEA - Finite Element Analysis, and the effect on a lined pipe under bending. Periodic disturbances were seen and small amplitude wrinkles became visible over time. Wrinkles were seen to grow in amplitude and thickness of the separation from the outer pipe increased. Wrinkling was seen to localise at mid-span and a diamond buckling mode became apparent.

As per Offshore Standard DNV-OS-F101 – Submarine Pipeline Systems, a wrinkle is defined as a type of localized buckling which is confined to a certain length in a pipeline causing changes to its cross-section. Some of the potential causes and main ways to reduce collapse of wrinkles are as given below:

- Internal roughness of the seamless outer pipe can cause imperfections in the liner. Hence it is critical that the imperfections in manufactured pipes are assessed and reduced as much as possible. In addition, the annular gap between the outer pipe and liner must be as miniscule as possible to delay a liner collapse.

Most pipelines are installed with capped ends and have no internal pressure at installation. Unfortunately, with the increased usage of lined pipelines for corrosion resistance, the tendency for the liner to get deformed has become quite high and indentations off most of the lined pipes used offshore are now mechanically bonded. But with the induction of modest levels of internal pressure the liner deformation and separation can be delayed and hence increased curvature can be achieved at the maximum moment [3].

**Assessing circumferential corrosion and wrinkling from a pipeline integrity perspective**

It is essential to conduct, a Corrosion and Integrity FFS – Fitness for Service Assessment, on pipelines where wrinkles have been identified. This can be conducted using published standards for example ASME B31G (Manual for determining remaining strength of corroded pipelines) and Offshore Standard DNV-OS-F101 – submarine pipeline systems. ASME B31G provides guidance in the evaluation of metal loss in pipelines and piping systems [4] although it may not be applicable to crack-like defects, metal loss due to grooving corrosion, selective corrosion or preferential weld corrosion, and pipelines operating at temperatures out with the normal operating range. Additional considerations have to be made with circumferential metal loss in pipelines that undergo high longitudinal stresses in compression. These could be areas of wrinkling or buckling. So ASME B31G would have to be supplemented with a more extensive ‘fitness for purpose’ guidance document like Kastner’s failure criterion methodology to analysing circumferential part-wall defects that are subject to internal pressure, axial and/or bending loads [4].

Considering any circumferential deformations noted in the intelligent pigging results near the welds, a likelihood of internal circumferential corrosion can be predicted in the event of the CRA liner being impinged during the cleaning pigging operation and a corrosion mechanism initiated. Circumferential internal corrosion is a contributory factor to hoop stress and axial stress conditions, which may ultimately lead to local failure of the pipeline.

Kastner’s failure criterion was initially developed taking into the internal pressure conditions in a pipeline. But this criterion has been proved by various researchers to be applicable to any axial load by replacing the axial stress due to internal pressure with the total axial stress.

Depending on the quality and quantity of data available for the analysis of a defect, ASME B31G has 4 levels of evaluation methods – Level 0, Level 1, Level 2 and Level 3. Level 0 is the most basic evaluation method and can be conducted without the need for calculations. Levels 1 & 2 can be used for prioritising metal loss anomalies. Level 3 is normally carried out by a specialist having the technical knowhow in Fitness for Service Assessments [5]).

**Conclusion**

In summary, where CRA lining is deployed, it is highly recommended to carry out intelligent pigging (IP) post installation to gauge the true condition of the CRA liner within the pipeline following pipe-lay, as there are possibilities for its integrity to be compromised.

An intelligent pig can provide the data for detailed analysis however this is a very costly exercise to perform. If detected, pig runs should be repeated at regular intervals to determine whether the wrinkles are increasing in size.

In addition to this, finite element analysis (FEA) should be considered to model the growth of the wrinkles in operational conditions. This includes inputting IP data and applying stress loading to the liner. Due to potential scaling issues within the inner wall of the pipeline, most operators now implement set pig cleaning routines at regular intervals, but if IP and FEA for a pipeline can be achieved, consideration can be made to reduce the cleaning pigging frequency to reduce the effect of the use of these aggressive tools and also give cost savings.

Factors that could potentially increase the growth of wrinkles or formation of new wrinkles should be reduced. For example, free spanning lengths in pipelines should be monitored and measures should be put in place to reduce the span length as the increase in span length causes the line to become prone to local buckling.

Pipe lay procedures must be reviewed for suitability in relation to selected materials prior to their adoption.

For future combination designs of carbon steel plus CRA liners, it is recommended to internally pressurize the lined pipe during cladding installation to avoid future issues of dis-bonding of the liner, potentially leading to wrinkling and liner disintegration through subsequent cleaning processes.

**Bibliography**

A Guide to the World of Epoxy Curing agents

W Allen, Sherwin-Williams Protective & Marine Coatings and S Darwen, CTP Chemicals and Technologies for Polymers GmbH

Epoxy coatings are the work-horse of the industrial and marine protective coatings industries. Their use is so diverse because of the many different properties that can be engineered into their structure.

Curing agents play a critical role in providing epoxy coatings with the properties to meet these varied demands, but it's not a simple world. There are many types of epoxy curing agents, and formulation complexities often make selection a difficult process.

This article presents a simplified breakdown of the basic types of epoxy curing agents and looks at them in terms of their general performance properties more so than their chemistry. The focus is on curing agents used in air-drying, solvent-borne, or solvent-free epoxies that cure at ambient temperatures. However, before looking at curing agents, some basic background on epoxy resins is in order.

Epoxy Resins

Epoxy resins used for coatings are commonly the diglycidyl ethers produced from epichlorohydrin and bisphenol A or bisphenol F. Specialised epoxy resins such as those based on tetrabromo bisphenol-A have been used in flame-retardant products because of their good resistance to burning. Other types of epoxy resins include those based on novolacs, diamines, diacids, and diols.

There are two major categories of epoxy coating, those that cure at ambient temperatures and those that require the application of heat to produce a “stoved” cure. Stoving materials, which include powder coatings, can & coil coatings, container coatings, and automotive primers, are beyond the scope of this article.

Epoxy systems that cure within an ambient temperature range of 0-40°C are very versatile. They can be formulated as anticorrosive primers, build coats and topcoats for steel or concrete. Typical applications include ship hulls and decks, ballast and cargo tanks, superstructures, surface buried and sub-sea pipelines, linings for tanks that hold food, potable water, wine, industrial floorings, and steelwork for bridges, etc.

These coatings are often applied in less than ideal conditions, such as low temperatures and or high humidity. The hazard level of the components is generally acceptable.
and manageable, and they can provide a wide variety of film properties. Within the category of ambient-temperature curing epoxies are single pack products such as epoxy esters, or those based on very high molecular weight epoxy resins, but by far, the most widely used epoxies, are the two pack products – i.e. those formulated with an epoxy resin plus a curing agent (or hardener). Two pack formulations can be used for solvent-free, solvent-borne, or water-borne coatings.

Epoxy Curing Agents

In almost all cases, epoxy resins must be crosslinked in order to develop the coating’s required characteristics. Single-pack coatings cure by oxidising or air drying, but in two-pack coatings, the crosslinking process is achieved by chemically reacting the resin with a suitable curing agent or hardener. The reactive groups of molecules in epoxy resin formulations are the terminal epoxide groups and the hydroxyl groups situated along the main chemical chain. These are illustrated in Figure 1.

For protective coatings, the principal crosslinking reaction is between the epoxide group and the curing agent. Amine-based curing agents are the most common type used in epoxy formulations. Therefore, they are the focus of this article.

Limited discussion is given to other types of epoxy curing agents. For example, epoxide groups can also crosslink with carboxyl groups, and mercaptan groups among isocyanates. These various formulations are used to produce coatings with different combinations of properties.

Figure 1 - The structure of the epoxide group (top) and secondary hydroxyl group (bottom).

Amine Chemistry

Primary amines are organic materials containing a nitrogen atom linked to two hydrogen atoms (-NH2). In epoxy formulations, the active hydrogen of the amine is what reacts with the epoxide group of the resin. The structure of the amine-containing organic compound and the number and type of amine groups in the compound are what determine the rate of crosslinking and the coating’s properties. Amines generally are chosen according to these structural differences. The more common ones are described below.

Polyamines, as the name suggests, are simply compounds containing more than one amine group. Since amine curing agents are actually based on polyamines, this is the term which will be used throughout the rest of this article.

Polyamine Curing Agents

There are three types of polyamines used to make curing agents: aliphatic (and araliphatic), cycloaliphatic and aromatic. From these we can derive curing agents classed as; modified polyamines, polyamine adducts, mannich bases and polyamides. Following is a description of each category, including subclasses of curing agents within each category where appropriate. Also presented is a description of the performance of epoxy coatings crosslinked with each category of curing agent in terms of the relevant following properties: pot life, cure rate, adhesion, tolerance for wet and low temperature application, chemical resistance, solvent resistance, heat resistance, flexibility and impact resistance, colour/aesthetics, and toxicity.

Factors to Consider in Selecting an Epoxy Coating

- Are particular health and safety features required (e.g., due to isocyanates, etc.)?
- Do environmental or usage conditions require a water-borne or a solvent-free product?
- What performance test standards must be satisfied (e.g., NORSOK M-501 or ISO 12944)?
- What in-service conditions and life expectancy are required?
- What physical properties are required (e.g., flexibility, abrasion resistance, toughness, heat resistance, etc.)?
- Are any special characteristics required (e.g., low spread of flame, potable water approval, chemical resistance, etc.)?
- What curing temperature is required, and what constraints on subsequent handling time must be considered?

Aliphatic Polyamines

The most common types of aliphatic polyamines used to make epoxy resin hardeners are polyethylenamines including ethylene diamine (EDA), diethylene triamine (DETA), triethylene tetramine (TETA), etc. In addition to these, trimethyl hexamethylene diamine (TMD) and the polyoxypropylene diamines are also often used. Because of the short, linear chemical chain between the amine groups in the polyethylenamines, coatings produced with them tend to have tightly crosslinked films with good resistance to heat and chemicals, including solvents. However, they are also rather brittle and have poor flexibility and impact resistance.

These short-chain, relatively basic amines, react readily at the surface/air interface with carbon dioxide and moisture in the atmosphere to form a surface condition known as amine bloom or blush. This blooming can not only detract from the aesthetic properties of the coating but also can interfere with inter-coat adhesion and lead to over-coating failure. While amine bloom is most common with aliphatic polyamines, it can affect other types of amine curing agents as well depending on the basicity of the amine.

Coatings formulated with aliphatic polyamines and cured at temperatures < 15°C are extremely susceptible to the problems listed above, although they can cure relatively quickly. In addition, they normally have relatively short pot lives. Because of their tendency to react with moisture, they are not suitable for application in damp or high humidity conditions.

In their raw form some aliphatic polyamines are considered skin sensitisers and respiratory irritants. The hazard is significantly reduced after the curing agent has reacted with the resin, but caution is needed on the part of applicators or anyone else who might handle these components before the coating is mixed.

As with all of the amines mentioned in this article, aliphatic polyamines can be modified to overcome or reduce their drawbacks. In fact, nowadays, aliphatic polyamines are mainly used in the production of other curing agents (e.g., see section on polyamides below).

Cycloaliphatic Polyamines

Cycloaliphatic polyamines are probably the most common type of polyamine used in ambient temperature curing agents for general purpose, straightforward epoxy formulations, one example of which is isophorone diamine (IPD).

These polyamines are often unsuitable for use as ambient temperature curing agents without modification as they require relatively high temperatures to enable epoxy coatings to cure completely. For this reason they are often modified with plasticisers, accelerators and/or by addition to overcome this drawback. Acid accelerators are often used for this purpose. An example could be salicylic acid dissolved in benzyl alcohol. The benzyl alcohol does not participate in the curing reaction, although it does protonate the amine and improve resistance.
Table 1 - Epoxy Coating Properties and Associated Curing Agents.

<table>
<thead>
<tr>
<th>Coating Property Required</th>
<th>Typical Curing Agent Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low VOC, high solids, or 100% solids</td>
<td>Cycloaliphatic polyamine (modified or adducted) Mannich base (phenalkamine) Polyamide/amido-amine (in conjunction with a viscosity-reducing reactive diluent)</td>
</tr>
<tr>
<td>Low temperature cure</td>
<td>Accelerated polyamine adduct Mannich base (phenalkamine) Accelerated polyamine</td>
</tr>
<tr>
<td>High temperature resistance (including high temperature immersion)</td>
<td>Aromatic or cycloaliphatic polyamine crosslinked with phenolic epoxy or epoxy novolac</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>Modified aromatic or aliphatic polyamine Mannich base (with epoxy novolac)</td>
</tr>
<tr>
<td>Solvent resistance</td>
<td>Aliphatic or aromatic polyamine (with epoxy novolac)</td>
</tr>
<tr>
<td>Potable water</td>
<td>Cycloaliphatic polyamine adduct (free of benzyl alcohol and nonyl phenol) Phenalkamine</td>
</tr>
<tr>
<td>Flame retardancy</td>
<td>most epoxy systems with appropriate formulation additives</td>
</tr>
<tr>
<td>Colour/aesthetics</td>
<td>Aliphatic and/or cycloaliphatic (hydrogenated epoxy resin)</td>
</tr>
</tbody>
</table>

Aromatic polyamines

Most aromatic polyamines are solid materials. Examples include m-phenylene diamine (MPD) and 4,4’-diaminodiphenyl methane (DDM). Since the amine groups in these compounds are separated by rigid benzene rings rather than flexible chains of molecules as in the aliphatic polyamines, coatings produced with aromatic polyamines tend to have good physical properties such as impact resistance as well as high resistance to heat and chemicals. Unfortunately because of their aromaticity, these compounds produce dark-coloured coatings.

Curing agents in this category are used to produce chemical and solvent-resistant coatings, and particularly when they are formulated with epoxy novolac and phenolic epoxy resins, they produce coatings that can resist high temperatures. Unmodified aromatic polyamines need high temperatures to cure. Therefore, they are modified with liquid plasticisers and acid accelerators and/or adducted with low molecular weight epoxy resins. Some of these modifications can cause a reduction in heat resistance, but chemical resistance is generally still good. The plasticiser is needed to offset the brittleness of the adducted formulation, but the type of plasticiser used can affect the acid and solvent resistance of the formulated coating.

Modified aromatic polyamines typically produce coatings with a medium pot life, slow curing rate, and a minimum curing temperature of 10°C. They have very good resistance to water and acidic media due to the low basicity of the amines. Hence they can work well in low temperature and damp conditions and are not susceptible to blooming. Toxicity is a serious drawback for some aromatic polyamines, such as DDM, which is generally considered to be carcinogenic and therefore, rarely used, at least not in its raw state. All aromatic polyamines are irritants in their uncured condition. However, once they have crosslinked with a resin and the coating has cured, they become less harmful. Furthermore, modification of aromatic polyamines can reduce their toxicity.

Polyamine Adducts

To overcome drawbacks found in aliphatic and cycloaliphatic polyamines, one common modification is to form polyamine adducts by reacting the polyamine with a small amount of epoxy resin. This gives rise to mixtures containing some higher molecular weight polyamine adducts which produce coatings with lower vapour pressure and hence less volatility and less likelihood of skin sensitisation (although this can still be a problem). They also produce coatings with more practical mixing ratios and a lower tendency to form amine bloom than simple unmodified polyamines.

The adduction has little effect on the other properties associated with polyamines since it is simply the first stage of the polymerization process. However, polyamine adducts do produce coatings with better aesthetic properties and colour retention than aromatic polyamines or polyamides.

As an alternative to using epoxy resin for adduction, a polyamine adduct can be formed with ethylene or propylene oxide. For example, a common adduct made from propylene oxide is β-hydroxyalkylamine. These adducts also have a reduced potential for skin irritation than unmodified polyamines but not necessarily improved compatibility with epoxy resin.

Polyamine adducts are usually prepared from either aliphatic or cycloaliphatic polyamines. These polyamine adducts are commonly used for solvent free coatings in a variety of applications and are considered to have a minimum practical curing temperature of 10°C.

Mannich bases

Mannich bases are a type of curing agent based on the reaction of a polyamine with a phenolic and formaldehyde. These curing agents can produce coatings that cure at low temperatures with no induction time. Most mannich base curing agents will also provide coatings with good broad spectrum chemical resistance. A particular type of mannich base curing agent are the phenalkamines where the phenolic used is produced to blushing. It remains in the film to act as a plasticiser, improving through-cure but lowering its heat resistance. Cycloaliphatic polyamines are skin irritants, so for commercial use they are usually are adducted (reacted) with a small amount of liquid epoxy resin to reduce the irritant effect, improve the compatibility with the epoxy resin and reduce blushing tendency.

Epoxy coatings with low levels of volatile organic compounds (VOCs) can be relatively viscous because of the mid-high viscosity of liquid epoxy resins. The basic resins can be modified with epoxy functional reactive monomers to reduce viscosity and to improve the handling properties. Since they have low viscosity at room temperature, cycloaliphatic polyamine curing agents are used in low VOC coatings and will further reduce the viscosity of the paint on mixing with the formulated epoxy resin.

Cycloaliphatic polyamine based curing agents typically produce coatings with a good cure rate, workable pot-life, and a minimum practical curing temperature of about 10°C. Lower curing temperatures are possible but the increasing risk of blooming has to be considered. The coatings they produce also have good resistance to chemicals, solvents, and water, which makes them suitable for use in various tank linings including potable water tanks, although in this case they must be compliant with the relevant local drinking water standards (taste/taint, positive list, extracts, etc.).

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from cashew nut oil. This phenolic structure incorporates a long carbon chain attached to the aromatic ring which when included into the cured epoxy coating will provide the impact resistance and corrosion protection properties not normally associated with standard mannich base curing agents. For this reason, they can be formulated in coatings for heavy-duty marine and maintenance primers with curing possible as low as -5°C. The chemical resistance of coatings made from phenalkamines is typically lower across a range of different chemicals than the standard mannich base curing agents.

Normally, standard mannich base curing agents produce coatings that cure at temperatures down to 0°C, but their colour and aesthetic properties are less than other type of curing agent because of their aromatic (phenolic) content.

**Polyamide Curing Agents**

Polyamides are formed by the reaction of polyamines and dimer acids, which are formed from tall oil fatty acids or fatty acids from natural sources such as soya beans or castor oil. The polyamines are mainly the polyethylene amines (e.g.,
polyamine curing agents are unmodified polyamides and amido-amines. The polyamides can also be adducted for the same reasons as in the case of polyamine adducts to form polyamide adducts. These adducts also have no induction time requirement unlike the standard polyamide curing agent. A description of each and a breakdown of their performance properties in terms of the same categories used above for polyamine curing agents, is given below.

Unmodified Polyamides

Unmodified polyamide curing agents produce coating films that are much more open in terms of their chemical structure than those made with polyamine curing agents as there is a large distance between the amine groups in the chemical chain. Consequently, unmodified polyamide-cured epoxies are more flexible and impact resistant than coatings made with simple aliphatic polyamines, which are tightly crosslinked. The open structure of these curing agents results in coatings with relatively low resistance to chemicals, solvents, and acids. However, their resistance to water and corrosion are enhanced by their surface wetting and adhesion properties. Unmodified polyamides generally produce coatings that are relatively slow curing and require a curing temperature of > 15°C. Adhesion of coatings made with these curing agents is very good, but their heat resistance is slightly lower than with unmodified polyamines, and they do not tolerate low temperature application.

Because the molecular weights of polyamides are much higher than those of linear aliphatic polyamines, mixing ratios are more practical, and pot life can vary up to 6-12 hours, making coatings formulated with these curing agents very user-friendly. Higher molecular weights mean greater viscosities and lower vapour pressures. Hence, there is lower irritation potential for coatings produced with these curing agents. Polyamides are used in low VOC coatings when reactive diluents are added to the epoxy resin to lower viscosity. Where amine bloom results from the use of polyamide curing agents, allowing for adequate induction time can offset this problem to some extent. (Surface bloom is the result of amine groups of the curing agent reacting with carbon dioxide and moisture in the atmosphere, and it is more prevalent with low molecular weight materials. However, during the induction period, addition takes place, the molecular weight of the mix increases, the availability of the amine groups decreases, and hence the tendency to bloom also decreases).

Amido-Amines

If a polyethylene amine is reacted with a mono-functional fatty acid rather than a dimer acid, then an amido-amine is formed rather than a polyamide. Amido-amine curing agents are less volatile and have less irritation potential than polyamines, and they have properties similar to polyamides. The viscosity of the amido-amines is much lower than typical polyamides and so amido-amines are often mixed with polyamides to reduce their viscosity. Amido-amine curing agents are used in high-solids and 100% solids epoxy, as well as in concrete coatings. If the reaction of the polyamine with the mono-functional acid is carried out for a prolonged period the imidazoline content of the amido-amine increases. Higher imidazoline content leads to slower reacting amido-amines which, combined with their low viscosity, make them useful in high-solids systems. Commercially amido-amine curing agents are available with various proportions of imidazoline and polyamide to allow a balance of properties to be achieved in the resulting coating.

Other Curing Agents

Additional kinds of curing agents often used with epoxy resins are worth noting. One type of non-amine curing agent often used with epoxy resins is the poly-mercapto group, which crosslinks with the epoxy group of the epoxy resin in a similar way to amine curing agents. Mercaptan based polymer curing agents, together with accelerators, can produce exceptionally fast-curing epoxies. They are used in adhesives and epoxy repair materials. They also are used with other curing agents, such as polyamides, to reduce induction times and to enhance curing. Finally, isocyanates, either in aliphatic or aromatic form, have been used for years to cure epoxy resins. The isocyanate reacts with the hydroxyl groups of the epoxy resin. Coatings formulated with these curing agents have very good low temperature curing, good flexibility, good impact and abrasion resistance, and good adhesion.

Summary

Two-pack epoxy coatings are made by crosslinking an epoxy resin with one of a variety of curing agents, depending on the particular properties desired in the cured product. Table 1 includes examples of typical epoxy curing agents used to produce particular coating properties. Amine chemistry is most commonly used in epoxy formulations. Four common types of polyamine curing agents are modified polyamine, polyamine adduct, mannich base and polyamide/amido-amine. However, sometimes, the choice of epoxy resin itself - not the curing agent - affects the properties of the resulting coating. Low molecular weight epoxy resins are used for high-solids, low-VOC, or solvent-Free coatings to ensure that their viscosity is low enough to be applied by conventional means, whereas phenolic epoxy or epoxy novolac resins produce coatings with good resistance to high temperatures improved chemical resistance.

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• The Long and the Short of Epoxy Resins, Shell Handbook, 1992
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Aberdeen Branch
Venue: Palm Court Hotel, 81 Seafor Road, Aberdeen, AB15 7YX
Speaker: Emma Perfect of LUX Assure
Topic: Function-related Dosage of Corrosion Inhibitors; The Development of An on-site, Operator Deployable Technology
Presentation to start at 6.30pm

8th March 2018

London Branch
Venue: Imperial College, Skempton Building, London SW7 2BB
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Presentation to start 6.30pm
For further details, see website or email icorr-london@gmail.com

27th March 2018

Aberdeen Branch Industrial Visit
Element Materials Technology
Industrial Visit to Element’s New H2S/Sour Service Lab in Aberdeen Visit to start from 6.30pm
Venue: Hareness Circle, Hareness Circle, Altens Industrial Estate, Aberdeen, AB12 3LY United Kingdom

24th April 2018

2018 CED Working Day Meeting
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29th May 2018

Aberdeen Branch – Joint meeting with NACE Industrial Visit
Industrial Visit to Sonomatic. Presentations and Showcasing Kit and Facilities on Overcoming and Identifying Corrosion/Integrity Challenges. Visit to start from 6.30pm Further details can be obtained from Aberdeen Branch.

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