Official Publication of The Australasian Corrosion Association Inc • www.corrosion.com.au

CORROSION & MATERIALS

Vol 41 No 1, February 2016
ISSN 1326 -1932

ASSET MANAGEMENT FEATURE

Inside this Issue:

AUSTRALASIAN CORROSION ASSOCIATION INC.
SEMPER TUENS

CORROSION & PREVENTION 2016

PROUDLY PRESENTED BY:

MAJOR SPONSOR:

13–16 November
SKYCITY
Convention Centre
Auckland,
New Zealand

Call for Papers – NOW OPEN

Call for Papers

Submissions are now welcome on all aspects of corrosion and its control for Corrosion & Prevention 2016. Papers are subject to peer review and if accepted will be published in the Conference Proceedings. Critical dates for acceptance of abstracts and papers are:

Close of Abstracts: 18 March 2016

Acceptance of Abstracts: 8 April 2016

Receipt of Papers: 10 June 2016

Submit an Abstract

Please refer to **www.acaconference.com.au** for further information about the submission process.

Guide to Submission

Papers submitted to the Corrosion & Prevention 2016 Conference must be unpublished works. It is the responsibility of the author to obtain necessary clearance/permission from their organisation. Copyright of the paper is assigned to the ACA. Abstracts should include the names of all authors, an appropriate title and a brief summary. All authors whose papers are accepted are required to present their paper at the conference.

The Destination

Kia Ora – Welcome to New Zealand

Feel the spirit of manaakitanga – the uniquely New Zealand form of hospitality.

As ancient explorers and early settlers discovered, you're never far from something incredible in New Zealand. New Zealand packs a lot of punch. It's a geographical and geological treat, with active and dormant volcanoes, thermal springs, wild rivers and glaciers, fine beaches and fertile plains. There's no better place for adventure, rejuvenation and inspiration. New Zealand is compact and easy to get around, so you can experience a whole lot in one trip.

Auckland

Home to 1.5 million people, the 'City of Sails' offers an opportunity to scale New Zealand's tallest building, the Sky Tower as well as savour fine food and wine in Auckland, New Zealand's largest city. Situated alongside two sparkling harbours and flanked by black sand beaches and native forest, this multicultural hub offers the perfect mix of urban chic and outdoor excitement.

Check it out

www.newzealand.com




Conference Convenor
Raed El Sarraf

Technical Chair
Raman Singh

Committee
Brian Hickinbottom
Erwin Gamboa

Technical Topics
Corrosion & Prevention 2016 invites technical papers on all subjects related to corrosion. The conference will bring together leading researchers and industry practitioners who combat corrosion on a daily basis. Diverse technical streams will showcase the latest developments in corrosion, ranging from fundamental corrosion science to hands-on application. Submissions may include research papers, review papers and case studies related to the technical streams and industry sectors listed below.

Technical Streams
- Advances in sensing & monitoring
- Asset and integrity management
- Cathodic protection
- Concrete corrosion and repair
- Corrosion mechanisms, modelling and prediction
- Corrosion prevention implementation
- Education, training and research
- Materials selection and design
- Protective coatings

Industry Sectors
This conference will have material of value to those working within the following industries:
- Buildings and construction
- Cultural and historical materials preservation
- Defence, aviation, maritime
- Education and research
- Food processing
- Government
- Marine, transportation and infrastructure
- Mining and resources
- Oil & Gas
- Power Generation and energy systems
- Water and wastewater

Sponsorship and Exhibition
Sponsorship will enable your company to make a significant contribution towards the success of Corrosion & Prevention 2016. In return, the conference offers strong branding and exposure in a focussed and professional environment. As with every Conference, the exhibition will be an integral part of the activities. It provides an opportunity for organisations to come face to face with the delegates; providing a marketplace to increase your organisation's visibility and to showcase and demonstrate your products and services.

For further information, please contact the Australasian Corrosion Association on +61 3 9890 4833 or email aca@corrosion.com.au

Your Hosts
The Australasian Corrosion Association Incorporated (ACA) is a not-for-profit, industry association, established in 1955 to service the needs of Australian and New Zealand companies, organisations and individuals involved in the fight against corrosion.

The mission of the ACA is to be leaders throughout Australasia in disseminating knowledge to enable best practice in corrosion management, thereby ensuring the environment is protected, public safety enhanced and economies improved.

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Email: conference@corrosion.com.au
Website: www.acaconference.com.au

Corrosion & Materials

Corrosion & Materials is the official publication of The Australasian Corrosion Association Inc (ACA). Published quarterly, *Corrosion & Materials* has a distribution of 2,500 to ACA members and other interested parties. Each issue features a range of news, information, articles, profiles and peer reviewed technical papers. *Corrosion & Materials* publishes original, previously unpublished papers under the categories 'Research' and 'Professional Practice'. All papers are peer reviewed by at least two anonymous referees prior to publication and qualify for inclusion in the list which an author and his or her institution can submit for the ARC 'Excellence in Research Australia' list of recognised research publications. Please refer to the Author Guidelines at www.corrosion.com.au before you submit a paper to Brendan Pejkovic at bpejkovic@corrosion.com.au with a copy to bruce.hinton@monash.edu

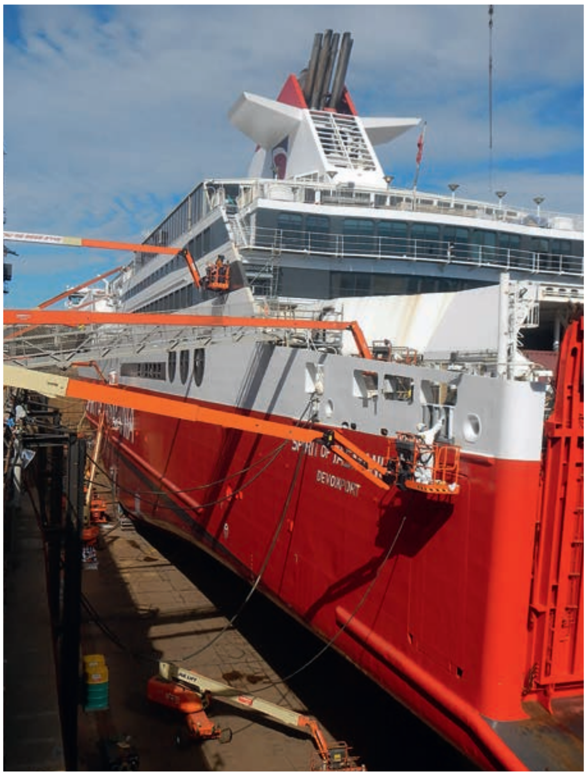
ACA also welcomes short articles (technical notes, practical pieces, project profiles, etc.) between 500 – 1,500 words with high resolution photos for editorial review. Please refer to the Article Guidelines at www.corrosion.com.au before you submit a short article to Brendan Pejkovic at bpejkovic@corrosion.com.au

The Australasian Corrosion Association Inc

The ACA is a not-for-profit, membership Association which disseminates information on corrosion and its prevention or control by providing training, seminars, conferences, publications and other activities.

Vision Statement

Reducing the impact of Corrosion.



Front Cover Photo:
Spirit of Tasmania *Paint Refurbishment, Captain Cook Graving Dock, Garden Island, Sydney, 2015, Coating system AkzoNobel. Contractor EPTEC Group.*

Image courtesy of *EPTEC Group.*

CORROSION & MATERIALS

ISSN 1326 -1932
Published by The Australasian Corrosion Association Inc.
ABN: 66 214 557 257

Advertising Sales
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Ph: 61 3 9890 4833 | Fax: 61 3 9890 7866

Subscriptions
Print Version: ISSN 1326-1932
Subscription rates:
Within Australia AUD $80.00 per annum incl GST
Outside Australia AUD $85.00 per annum excl GST posted airmail

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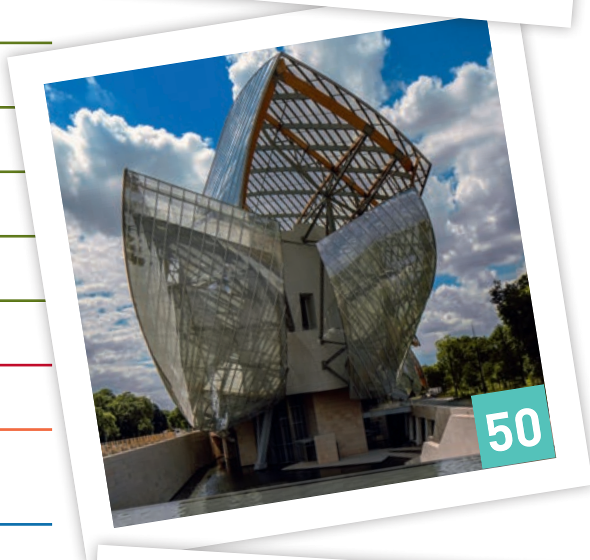


John Duncan
President

It is an honour to serve as President until the 2016 conference next November in Auckland. I look forward to seeing many of you again at the conference.

Bruce Kean AM, then Managing Director of Boral Ltd, made a perceptive observation to the Australian Master Builders Construction and Housing Association Centennial Conference in Melbourne in 1990: '*As performance is pushed further and further out, so the need for narrower and narrower performance limits becomes critical… As designs are pushed to the limit, quality control and maintenance become critical elements in the construction and life of the structure.*' It seems to me that this observation from 25 years ago is a message we in ACA need to again be 'putting up in lights'. We are already making some progress, but there's room for more.

In New Zealand, it is pleasing to see NZ Transport Agency now requiring that those responsible for overseeing paint application on their structures are to have appropriate qualifications. This should advance considerably the quality assurance of their structures. If all asset owners adopted a similar approach – but they don't – we'd start to begin saving the huge fraction of GDP which overseas surveys suggest our economies lose unnecessarily to materials degradation each year.

We need more employers to be encouraging their staff to be better engaged in the training and knowledge transfer activities that bodies such as ACA and the like offer. I cannot see how that will not be win-win-win for all concerned – the employer getting a more qualified staff, the client getting a better product, and the nation saving some of that wasted GDP.

We are also, unfortunately, seeing past problems repeated as practitioners come through the ranks without learning from mistakes made by their predecessors. Take a look at the paper from our Adelaide conference about failure of a stainless steel ceiling suspension over a swimming pool[1], and look at the references there to earlier fatalities in Europe using a similar system. Innovation sometimes doesn't go the way we intend; that's natural, but it is unforgiveable not to learn from it and avoid its repetition.

On behalf of all ACA members, I say 'thank you' to those who, often with little recognition, lead our Branch and Technical Group activities, edit our technical outputs, and ensure that ACA contributes appropriately to development of Codes and Standards. All these activities can make the necessary difference. There is always room for more to participate. If you have skills or ideas that you think will take ACA forward, please don't hesitate to raise them with your Branch Committee, with the ACA Centre staff, with Board members, or with me. ACA won't be able to do everything we'd like to, but having a wide smorgasbord of activities to choose will make us better refine how we prioritise using our relatively slim resources.

John Duncan
President

[1] Cram, D. (2015). When cheaper is better: stress corrosion cracking in hanger rods. Corrosion and Prevention 2015, Paper 142. Australasian Corrosion Association, Adelaide.

ACA 2016 Events

Part of the role of the ACA is to organise events that bring together industry experts to present on new technologies, updates to standards, and share knowledge and experiences via case studies on a variety of projects. Here are the events that are planned so far for 2016.

Month	Event Title	Event Date	Event Location
March	MIAL / ACA Joint Event – Maritime & Marine Corrosion	Thursday 10 March	Melbourne
April	Corrosion Prevention Event	Thursday 21 April	Newcastle
May	Corrosion Prevention Event Oil & Gas Event	Thursday 19 May Thursday 26 May	Auckland Perth
June	Power Event Coatings Event	Thursday 9 June Thursday 23 June	Brisbane Melbourne
July	Introduction to Corrosion Introduction to Corrosion APGA / ACA Joint Event – Pipeline Corrosion Management	13 & 14 July Thursday 21 July Thursday 21 July	Newcastle & Sydney Hobart Perth
August	Oil & Gas Event Water Event	Thursday 4 August Thursday 18 August	New Plymouth Sydney
September	Concrete Event	Thursday 1 September	Adelaide or Melbourne
November	Corrosion & Prevention 2016 Introduction to Corrosion	13 - 16 November Tuesday 15 November	Auckland Auckland

ACA members will receive further details on each event as appropriate throughout the year, but for now, please include these in your 2016 diary. For further information on these events for 2016 please don't hesitate to contact Brendan Pejkovic (bpejkovic@corrosion.com.au) in the ACA office on +61 3 9890 4833.

Branch Events

Each of the 8 ACA Branches will conduct regular technical events throughout 2016. To enquire, you may contact your local Branch at the following email addresses:

New South Wales: nsw@corrosion.com.au
New Zealand: nz@corrosion.com.au
Newcastle: ncl@corrosion.com.au
Queensland: qld@corrosion.com.au
South Australia: sa@corrosion.com.au
Tasmania: tas@corrosion.com.au
Victoria: vic@corrosion.com.au
Western Australia: wa@corrosion.com.au

YCG Events

Targeting individuals under 35, new to the corrosion industry and/or interested in the corrosion industry, the ACA Young Corrosion Professionals conduct regular events. For further details email ycg@corrosion.com.au or go to www.corrosion.com.au

THE AUSTRALASIAN CORROSION ASSOCIATION INC
YOUNG CORROSION GROUP

Please refer to **www.corrosion.com.au** for up to date details on all ACA activities.

Wesley Fawaz
Executive Officer

2016 is shaping up to be another busy year for the ACA as we implement further foundations for the future.

I had a telephone meeting with South Australian Senator Nick Xenophon (following his speech at our 2015 conference) early January and he confirmed his strong interest to support the ACA's goals. The ACA will now provide Senator Xenophon with information to submit to Parliament in Canberra on our behalf.

The ACA is diversifying its training offerings in 2016 and is currently implementing the groundwork to schedule courses linked to the recently signed training agreement with NACE International:

- A Hot Dip Galvanizing Inspection course is being trialed in February and will be scheduled across Australia and New Zealand very soon.
- The SSPC Concrete Coating Inspection course has been scheduled for March (Brisbane), May (Perth) and September (Sydney).
- CP lecturers are attending a 'Train the Trainer' program late February as part of the process to lecture the NACE CP program in Australia/New Zealand. NACE CP courses will be announced and scheduled also very soon.
- The Coating Selection & Specification course which is closely linked to the Standards AS/NZS 2312 is currently undergoing a revision following the update of the Standard last year. This should be completed in March and announced and scheduled shortly.
- ACA Training Coordinator Skye Russell was in Thailand in January meeting local blast yards, facilities and key personnel in preparation for offering the NACE CIP, CP and Pipeline programs.
- NACE Pipeline courses will also be offered in 2016.

Based on the results of last year's training survey, the ACA is also planning for future course development and offerings to ensure an expanded professional development program is offered to ACA members and industry.

This year the ACA will be bidding to host the 19th Asian Pacific Corrosion Control Conference as well as the 21st International Corrosion Congress, both in 2020. If the ACA is successful with these bids, the 2020 conference (joint ACA/APCCC/ICC) is set to be the biggest conference ever managed by the ACA.

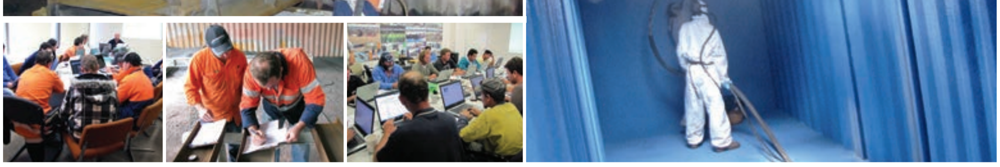
Call for Abstracts are open for the Corrosion Prevention 2016 conference in Auckland and close on Friday 18 March. Abstracts can be submitted and for further details of the conference, please go to www.acaconference.com.au

The first one day technical and networking event for the year is next month in Melbourne. Focusing on 'Corrosion in the Maritime Industry', this is a joint event with the Maritime Industry Association which will attract a wide audience connecting members from both Associations.

The 2015 financial audit is currently underway with ACA auditors Baumgartner Partners. This year's AGM will be held in Brisbane on Thursday 26 May with details announced closer to the AGM.

A reminder that '*Corrosion & Materials*' is now published quarterly with the next issue to be published in May. Until then, best wishes for the year ahead.

Wesley Fawaz
Executive Officer
wesley.fawaz@corrosion.com.au



THE AUSTRALASIAN CORROSION ASSOCIATION INC.

TRAINING

ACA Training Calendar 2016

ACA/ACRA Corrosion and Protection of Concrete Structures

Member $1115 Non-member $1395

Sydney April 14 – 15

Melbourne June 23 – 24

Adelaide October 24 – 25

New Zealand November 10 – 11

ACA Coating Inspection Refresher

Member $605 Non-member $740

Australia TBA

New Zealand TBA

NACE Cathodic Protection Program Level 1 – 4

Scheduled courses of the NACE Cathodic Protection Program will soon be available in Australia and New Zealand. To express your interest, please email aca@corrosion.com.au

NACE INTERNATIONAL®

Corrosion Technology Certificate *(Also offered as Home Study)*

Member $2330 Non-member $2730

Melbourne April 4 – 8

New Zealand July 18 – 22

Sydney November 28 – December 2

CTC Home Study

Member $2330 Non-member $2730

Start any time

Metallurgy of Steels Introduction

Member $1560 Non-member $1900

Melbourne September 26 – 28

NACE Coating Inspection Program Level 1

Member $3740 Non-member $4275

Brisbane February 22 – 27

Melbourne April 18 – 23

Sydney May 23 – 28

Perth June 27 – July 2

Adelaide August 15 – 20

Brisbane September 12 – 17

Melbourne October 10 – 15

New Zealand October 31 – November 5

Sydney December 5 – 10

NACE Coating Inspection Program Level 2

Member $3740 Non-member $4275

Brisbane February 29 – March 5

Sydney May 30 – June 4

Perth July 4 – 9

Brisbane September 19 – 24

Melbourne October 17 – 22

New Zealand November 7 – 12

Prerequisites now apply to this course.

NACE Coating Inspection Program Level 3 Peer Review

Member $1470 Non-member $1725

Sydney July 25 – 29

By appointment only. Duration: 2 hour oral exam in front of a 3 member review board. Pre-requisites apply go to Training at www.corrosion.com.au for more details

Protective Coatings Quality Control

Member $1560 Non-member $1900

Sydney April 11 – 13

Brisbane August 29 – 31

SSPC Concrete Coatings Inspection

Level 1 $3000 Level 2 $3500

Brisbane March 14 – 19

Perth May 2 – 7

Sydney September 12 – 17

SSPC The Society For Protective Coatings

ACA In house Training

The ACA can present any of its courses exclusively for an organisation; we can also tailor any course to your organisation's specific needs. Please contact the ACA's training department on **+61 3 9890 4833** or **aca@corrosion.com.au**

All Australian course fees listed are GST inclusive. All NZ course fees are exempt from GST.

To calculate the fee pre-GST, divide the fee by 1.1

Board Changes at the ACA Foundation Ltd.

The ACA Foundation Ltd Directors are delighted to report that at the Foundation's December 2015 Board Meeting, a unanimous vote elected Warren Green, Vinsi Partners to the position of Chair and Sarah Furman, AECOM to the position of Deputy Chair. In 2016 the ACA Foundation has appointed a Project Officer, Simone Di Nucci to work alongside Jacquie Martin, to assist the Board to realise its Business Plan and achieve its objective of advancing corrosion mitigation through education.

ACA FOUNDATION LIMITED

Launching a new era of 'Wattyl Protective Coatings'

New GM Mike Bartels

Valspar has appointed Mike Bartels as General Manager for its Protective Coatings business. Previously known as Wattyl Industrial Coatings, Valspar has reinforced its commitment to Protective Coatings through strategic business plans, talent investment and increased technology and innovation. Mike Bartels will head Valspar's Australasian Wattyl Protective Coatings business.

Mike's career in Protective Coatings spans over 30 years. He previously held various senior roles within AkzoNobel's International Paint, including, Australasian Business Manager, Marketing Manager (Global) and Business Development Manager, Asia. His career with Valspar began in 2015 in Melbourne as Business Development Manager, leading to his recent appointment as General Manager. Mike said, "As a local manufacturer of protective coatings, we will focus on developing and supporting products that meet the demands of the Australasian market. With recent investment in our manufacturing capacity and local R&D facilities we are well positioned to support the needs of our Customers".

Valspar's Managing Director, Richard Meagher, commented: "The appointment of Mike Bartels was an important milestone for Valspar as I am confident he will be the catalyst in helping steer Wattyl's Protective Coatings business to the next stage of professional excellence. Mike comes with outstanding credentials. He will bring focus and experience to our activities within the Protective Coatings market; a market which Valspar is now committed to growing globally."

The new Wattyl Protective Coatings brand will be visible in the marketplace from 2016.

Valspar is a global leader in the coatings industry providing customers with innovative, high-quality products and value-added services. Our 10,800 employees worldwide deliver advanced coatings solutions with best-in-class appearance, performance, protection and sustainability to customers in more than 100 countries. Valspar offers a broad range of superior coatings products for the consumer market, and highly-engineered solutions for the construction, industrial, packaging and transportation markets. Founded in 1806, Valspar is headquartered in Minneapolis, USA. Valspar's reported net sales in fiscal 2014 were $4.5 billion and its shares are traded on the New York Stock Exchange.

wattyl® Protective Coatings

Rust inhibitors a waste of cash

The Sunday Mail (Queensland)
6 Dec 2015.

It promises to reduce rust and corrosion in cars by up to 80 per cent, but according to NSW Fair Trading Commissioner Rod Stowe, computerised electronic corrosion inhibitors (CECI devices), are a waste of money.

His warning follows moves by his West Australian counterparts to stop distributors High Performance Corporation Pty Ltd, and Motor One Group Pty Ltd from selling the devices.

Mr Stowe said CECI devices were often sold through car dealerships, auto parts stores and window tinting companies. The devices are usually connected to the car's battery and a power point.

WA Consumer Protection sought independent expert opinion and testing that concluded CECI units did not prevent rust or corrosion.

The makers of other, similar products are also being investigated by WA Consumer Protection.

Mr Stowe said prices had ranged up to $4000.

Both companies have agreed to stop supplying, advertising or promoting the CECI devices from December 31. Consumers who bought the devices between January 1, 2011 and December 31, 2013 are entitled to a full refund.

Protective coating applicators Mattioli getting a true picture with eyes in the sky

A new in-house innovative tool for the estimating team has been adopted this month at Mattioli's. The team have invested in the latest drone camera technology to help the team identify corrosion issues up close and personal around the hard to reach & see areas on regional assets. The benefits to Gianni and his team will be to get a true picture of the work to be undertaken, minimising any risk of overruns or variation on pricing protective coating works as well as improve safety for the team by eliminating the need of scissor or boom lifts to inspect and scope projects. If you're a regional customer it'll be likely heading your way to help Gianni and his Industrial team in 2016.

Auckland Light Rail Network DC Interference & Stray Current –Stakeholder Meeting

In November 2015 the NZ Electrolysis Committee (NZEC) was approached by Auckland Transport's technical advisers (Arup) to assist with organising a meeting of utility owners who may be affected by stray current from the planned Auckland Light Rail Network. The meeting was held on 3 December 2015.

The Light Rail Network will use direct current electric traction at a nominal 750VDC. Historically there have been significant corrosion issues from dc rail traction systems and despite significant improvements in design and construction practices there remains a risk to metal services, such as steel pipelines and lead sheathed telephone cables and to a lesser extent rubber-ring jointed steel, ductile iron and cast iron pipelines.

Arup and Auckland Transport are keen to avoid issues that some overseas projects have had where utility owners were not engaged with early enough in the design process. This meeting was organised to ensure that all the major stakeholders are aware of the project and are involved in the design and management of stray current mitigation. The meeting was attended by representatives from Vector Gas Ltd, Watercare Services Ltd, Chorus Ltd, Refinery NZ and several corrosion prevention service companies, as well as Auckland Transport and Arup.

Following introductions, David Stuart-Smith of Arup outlined the scope of the Auckland Light Rail Network, the expected stray current issues, and Arup & Auckland Transport's expectations for management of the issues. David commented that Arup were pleasantly surprised to find that there was an electrolysis committee in New Zealand, and expects that it will be of great assistance in ensuring the involvement of affected utility operators.

The design of the rail network includes insulation of the rails from the concrete slab in which they are embedded, however because of the length of the rails the effective resistance to ground of the rails is quite low and some current will leak to ground. In practice pipelines or cables must cross or pass within tens of metres of the rails to pick up stray current – corrosion may occur at some distance from this, where the current that was picked up discharges from the structure. The actual voltage shifts in the structures will be very low – too low to present any danger to personnel maintaining the structure. During construction there will be a need to move a large number of services, which presents an ideal opportunity to install stray current mitigation, such as insulating joints.

The project is in early design, with construction expected to commence in a couple of years and be completed in the early 2020's. Arup are currently working on a framework for managing stray current, which will be issued to the NZ Electrolysis Committee and the key stakeholders and will form the basis for management through the design and construction periods.

The meeting was a good introduction to Arup, Auckland Transport, pipeline and cable operators, and the NZ Electrolysis Committee. The NZ Electrolysis Committee will continue the relationship with Arup and Auckland Transport and work with them to ensure that affected utility operators remain engaged in the process of achieving effective management of the corrosion risks from stray current.

IN MEMORIAM GEORGE GEOFFREY PAGE

24 November 1926 – 28 March 2015

It is with sadness that we record the passing of Geoffrey Page, aged 89, at North Shore hospital, Auckland, in March 2015. Geoff was a well known corrosion expert who practised in the UK and in New Zealand during his lifetime. Geoff was born in England and he was an active serviceman in the British Navy during World War II. He saw plenty of action during the war and at D-Day in Normandy he was in command of a small boat. After the war Geoff visited New Zealand where he worked on a farm while he was studying for his degree. Later on while re-visiting England he met his wife-to-be Jean in Edinburgh and they settled on the South Coast of England where they enjoyed boating on Chichester Harbour. During this period Geoff also worked in Birmingham and London on various assignments related to marine engineering.

In 1968 the chance of a job came up at the former DSIR (Department of Scientific & Industrial Research) in New Zealand. Geoff and Jean emigrated to NZ and lived in Wellington where he worked at the Industrial Processing Division (IPD) of DSIR, specialising in corrosion engineering projects. During his long career Geoff published many reports and scientific papers on aspects of corrosion engineering. In 1984 he authored a DSIR Industrial Information booklet entitled 'Handling and Fabricating Stainless Steels for the Food Industry' which became a valuable tool for food processing and dairy industry engineers. Geoff was also a leading expert on corrosion of copper water tubing used in building services, a subject on which he wrote a number of scientific papers. During his long career Geoff carried out a number of materials projects around the globe and he travelled extensively to give presentations at local seminars in NZ and at international conferences.

In the 1970s and 1980s Geoff was active in the NZ Branch of the Australasian Corrosion Association. At the ACA Annual Conference held in Auckland in 1976, Geoff was presented with the ACA's prestigious Corrosion Medal, which was given in recognition of his corrosion research at DSIR. After retirement Geoff spent his time at Rothesay Bay in Auckland, where he particularly enjoyed wind surfing.

Geoff will be remembered for his productivity, his practical hands-on approach to solving corrosion problems, his strong heritage of technical landmarks, and his good humour. Geoff is survived by his wife Jean, his two sons Nicholas and Peter, and five grandchildren whom Jean describes as "solid Kiwis all".

Les Boulton

ACA Welcomes New Members

Corporate Platinum

Dustless Blasting
www.dustlessblasting.com.au
Dustless Blasting is an Australian owned and operated company specialising in Dustless Blasting machines and equipment for a variety of industries wanting the very best in abrasive blasting technology. These Dustless Blasting machines are high quality American made machines and have more than 60 years in product development to bring you the world's leading products and accessories.

Corporate Silver

Equilam North America
www.equilamna.com
Since 1987, Equilam has been a recognised leader in the worldwide corrosion testing industry supplying state of the art equipment to its vast number of customers in many different industries. With their expansion into the North America, they continue on this path, providing their customers dependable corrosion testing equipment and corrosion testing services with the highest craftsmanship available. Equilam has always been recognised for its quality, durability and ability to turn ideas into unique designs and functional solutions.

WOMA Australia Pty Ltd
www.woma.com.au
WOMA is committed to the provision of design, assembly, sale, training, service and rental support of High and Ultra High Pressure Water & Vacuum Pump Technology, associated robotics and manipulators. Their broad range of nozzles, accessories, associated jetting systems and manually or remote controlled tools and equipment will give you the edge.

Corporate Bronze

Australian Maritime Safety Authority
www.amsa.gov.au
The Australian Maritime Safety Authority (AMSA) is a statutory authority established under the Australian Maritime Safety Authority Act 1990 (the AMSA Act). AMSA's principal functions are: promoting maritime safety and protection of the marine environment preventing and combating ship-sourced pollution in the marine environment providing infrastructure to support safety of navigation in Australian waters providing a national search and rescue service to the maritime and aviation sectors.

Energy Infrastructure Management Pty Ltd
www.energyim.com.au
EIM's core business is the operation and maintenance of vital resource carrying pipelines across Queensland. EIM supplies competent staff with industry experience to ensure the best care is taken of the assets and pipelines under their management. This work includes the remote monitoring of assets and equipment to ensure they are accurate, maintained operating at all times. On the ground are experienced and knowledgeable professionals, trained in environmental legislation and compliance; and all underscored by a strong Health and Safety Management culture.

Highline Rope Access - New Zealand
www.highlineropeaccess.co.nz
Built on over 15 years of industrial rope access experience, Highline Rope Access is a highly proficient work at heights service provider. They comprise of a team of time served industry professionals endeavoring to build an innovative, customer focused service to a range of fields, including power generation, commercial property, bridges and heritage sites.

Iontech Engineering Solutions Pty Ltd
www.iontech.net.au
IONTECH is a company with a focus on Engineering Solutions providing environmentally friendly preservation applications in Manufacturing, Mining, Oil and Gas, Agriculture and any other industry where corrosion is an issue or could represent an environment or health threat. They are committed to results. The advancement of anti-corrosive technology with an environmental focus is at our core. IONTECH has exclusive access to a number of technology patents, including V-Active, providing a uniquely environmentally friendly product for use in water based corrosion prevention liquids.

Paint Supplies Pty Ltd
www.paintsupplies.com.au
Paint Supplies had a modest beginning in 1990 in the backyard shed of owners Gary & Vicky Johanson. Since 1995, the business has been located in their huge warehouse on West Lakes Boulevard in Hendon SA where it now serves the needs of small, domestic D.I.Y. painters to very large corporate clients and everyone in-between. A large part of the business involves sending paints to all parts of Australia as part of the popular 'Stay at home – Shop by phone' service.

PIVOTROM Pty Ltd
Pivotrom Pty Ltd is a recently established Hunter Valley based company specialising in all aspects of cathodic protection. Pivotrom is run by the same directors and management team as Spectrom Pty Ltd, which has been a leading service provider to the civil, manufacturing and mining industries from the past 30 years.

Professional Diving Services
www.profdivers.com
Professional Diving Services (PDS) have been in operation for in excess of thirty years supplying commercial diving services predominately throughout Victoria but also interstate and overseas. Professional Diving Services management, supervisory and diving staff, are familiar with the waters of the Victorian coastline and have conducted offshore works from Portland to Lakes Entrance The mission of Professional Divers Group is to offer a service of excellence in commercial diving, underwater construction, salvage and diving instruction to our customers. In addition, the occupational training division, Smarter Safer Solutions, and Professional Divers Training Academy offers educational and occupational health and safety services of exceptional quality to industry best practice.

ACA Seminar Darwin

Darwin turned on a storm to welcome attendees to this ACA event held at the Darwin Sailing Club on the 26 November. As a good omen, the skies had cleared by the time the seminar started. The seminar was well timed, given that only the previous Friday the Northern Territory Chief Minister had announced that the North East Gas pipeline inter-connect (NEGI) will be built from Tennant Creek to Mt Isa. Professor Suresh Thennadil, Director of the North Australia Centre for Oil and Gas (NACOG), opened proceedings with an overview of the activities of NACOG.

Lex Edmond, from Deakin University/ Energy Pipelines CRC, gave the first presentation on polyethylene coatings for large diameter steel pipe. It was noteworthy that Steel Mains now seemed to be the only remaining large local pipe manufacturer/coater, as Bredero Shaw no longer coat pipe in Australia.

This was followed by Associate Professor Krishnan Kannoorpatti from NACOG/Charles Darwin University (CDU) who presented two corrosion case studies involving stainless steels. One study in particular had a local flavour as it involved the corrosion of part a welded cage used to enclose a crocodile!

Then came CDU Graduate Student Varmaa Martimuthu, who has been developing Pourbaix diagrams to study the corrosion of hard carbide coatings, used in the mining industry. The evening concluded with a talk by Jacinta Kelly who presented her interesting work on the creation of a more accurate model for the prediction of corrosion rates in CO_2 containing pipelines.

Thanks go to the event sponsors: Everett's Mechanical & Corrosion Consulting, Neptune Asset Integrity Services, and the North Australia Centre for Oil and Gas (at CDU).

Associate Professor Krishnan Kannoorpatti from NACOG.

Jacinta Kelly talking about the use of neural network modelling to predict corrosion rates.

Victorian YCG 'Corrosion Cruise'

The Victorian Branch YCG topped off another successful year with a 'Corrosion Cruise' travelling along the Yarra River from Docklands near the Melbourne CBD through to the Port of Melbourne and out to Williamstown on Port Phillip Bay.

On Friday night 23rd October, aboard the MV Barkoona, around 40 young, and young at heart corrosionists toured the port while enjoying a buffet BBQ dinner and a few drinks. Throughout the cruise there was plenty of time for networking and we were lucky enough to have several presentations outlining some of the significant corrosion management projects that have been undertaken around the port area over the last few years.

The projects included innovative coating systems applied to sheet piles at Webb Dock, cathodic protection contractual challenges also at Webb Dock and a summary of cathodic protection tales from BAE Ship building facility.

Thanks go out to our three speakers, Dragan Stevanovic, Brendan McGuinness and Ain Beruldsen, Steve Wallace our tour guide from PoMC and our generous sponsors for the night, PPG Industries, Freyssinet and Select Solutions for making the night such a success.

Wrapping up the year we would also like to thank everyone who has supported our events and helped out throughout the year. We are looking forward to another busy year in 2016 and hope to see you there.

Adrian Vinnell
Vic Branch YCG Representative









A.S. DIAMANTINA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CORROSION & PREVENTION 2015

Proudly presented by:

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CONFERENCE REVIEW

Overview

The ACA and its New South Wales Branch welcomed over 550 delegates, exhibitors, partners, visitors and staff to the city of Adelaide for Corrosion & Prevention 2015 (C&P2015). The annual conference is established as the Australasian corrosion industry's premier technical event and 2015 was no exception. Held over three days at the Adelaide Convention Centre, C&P2015 covered a range of technical topics including a cutting-edge blend of the latest research and industry practice presentations including six plenary lectures, six technical forums and 80 individual paper presentations.

As always, the social element of the conference was well enjoyed by delegates. The Sunday evening First Time Delegates Function (sponsored by the Galvanizers Association of Australia & Adelaide Galvanising Industries) held at the Convention Centre, was well attended and gave first time delegates the opportunity to be briefed about the conference format and the benefits of networking with peers at the conference. The Welcome Function sponsored by Incospec Corrosion Engineers was held at the Hotel Richmond, in a vibrant setting with views of Rundle Mall. Monday's Exhibition Opening and Young Corrosion Group (sponsored by the Galvanizers Association of Australia & Korvest Galvanisers) events were also well received. On Tuesday evening the ACA Annual Awards Dinner sponsored by Denso Australia was held with live entertainment from the comedy and musical act, 'The Three Waiters'. Finally the Farewell Function on Wednesday closed the conference with friends old and new saying farewell to each other.

Plenary Speakers

The conference was officially opened on Monday morning by Senator Nick Xenophon, this opening speech is available to view on the ACA website. ACA President Mohammad Ali welcomed all delegates, exhibitors and speakers to the conference. Other welcome messages came from Conference Convenor Alan Bird, Ted Riding, Jotun, C&P2015's major sponsor and conference technical committee chair, Erwin Gamboa. The traditional ACA Corrosion Clock, powered by a galvanic corrosion cell, was officially started by Bruce Hinton. The clock is used to keep time at every ACA conference.

After the official opening, proceedings commenced with plenary lecturer Markus Büchler from the Swiss Society for Corrosion Protection, Switzerland, speaking on the mechanisms involved in cathodic protection. This was followed by Miles Buckhurst of Jotun presenting on the true cost of paint, a life cycle philosophy. On Tuesday morning delegates were treated to the annual PF Thompson Lecture delivered this year by Dr Robert Francis. Rob venerably upheld the tradition of the PFT lecture, started by Dr Edmund Potter in 1970, using a very animated presentation style in conjunction with practical musical demonstrations to illustrate electrochemistry. The PFT is recognised as the highlight of the technical program each year. After completion of the PFT, Professor Baldev Raj from the National Institute of Advanced Studies in India spoke about corrosion mitigation, monitoring and inspection technologies. Wednesday morning saw a change in the advertised program, with Professor Srdjan Nesic unable to travel to Australia. Instead






Dr Laura Machuca and Dr Katerina Lepkova of Curtin University presented their work on the corrosion of HMAS Sydney and HSK Kormoran and how this research could be applied in a wider sense to corrosion of steel in deep ocean seawater and the influence of bacteria on under deposit corrosion in oil producing pipelines. This was followed by Warren Green, who delivered Frank Collins paper on 3D visualisation of reinforced corrosion within concrete marine structures.

The conference technical committee thanks all of the plenary lecturers, both local and international, for their outstanding presentations.

Forums and Technical Program

The technical paper program was substantial as always and sessions were arranged to bring theory and practice together. Corrosion & Prevention 2015 saw the delivery of 80 papers in Adelaide. Major areas such as corrosion mechanisms, materials, coatings, cathodic protection, asset management, pipelines and, concrete structures were spread over the three days of the conference.

A feature of Corrosion & Prevention 2015 was the technical forums organised by the ACA Technical Groups. Forums held included Coatings, Cathodic Protection, Concrete Structure & Buildings, Oil & Gas, Asset Management and Research. The discussions in these sessions were robust as usual and very worthwhile for the attendees. These forums are an ideal setting for both formal and informal exchange of experiences, case studies, problems, ideas and solutions with experts in each field.

Trade Exhibition

Corrosion & Prevention 2015 featured a large trade show with 69 exhibition booths. These included materials suppliers, equipment vendors, specialist contractors and consultants. Delegates were able to browse the stands throughout the conference and take the opportunity to discuss products and services with the exhibitors. Exhibitors benefited from broad exposure to corrosion industry practitioners from around Australia, New Zealand and the world.

Conclusion

On behalf of the ACA and the conference committee, thanks are extended to C&P2015's Major Sponsor - Jotun, Supporting Sponsors - 3C Corrosion Control Company; Cryoprep; PPG Protective & Marine Coatings and Russell Fraser Sales. Thanks as well to C&P2015 other sponsors; Denso Australia, Incospec Corrosion Engineers, Galvanizers Association of Australia in partnership with Adelaide Galvanising Industries and Korvest Galvanisers, Anode Engineering, Blast One, Dulux, Freyssinet, Phoenix Australasia and Zinga and all the exhibitors for their support of the conference. Thanks also go to the plenary lecturers, speakers, session chairs and all delegates without whom the conference would not exist. A special mention must be made of the ACA conference committee and ACA staff for their outstanding work in organising the conference.

In 2016 the conference will be held in Auckland, New Zealand. Corrosion & Prevention 2016 will be held from 13-16 November at the Sky City Convention Centre.

For more information refer go to the ACA conference website www.acaconference.com.au

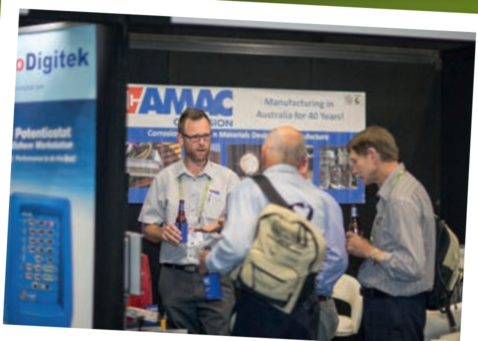
CORROSION & PREVENTION 2015 PHOTOS


JOTUN
JOTATEMP 650
Surface Tolerant Coating
for Corrosion Protection
at Extreme Temperatures


USTRALASIAN
ORROSION
SSOCIATION INC.


JOTUN
JOTUN


JOTUN
Steelmaster 1200 WF
Reliable and efficient


Digitek
AMAC
Manufacturing in Australia for 40 Years!


AUSTRALASIAN
CORROSION
ASSOCIATION INC.


AUSTRALASIAN


JOTUN
Surface Tolerant Coating
for Corrosion Protection

CORROSION & PREVENTION 2015 PHOTOS



THE LITTLE
HUNTER
Steak & Ale Bar







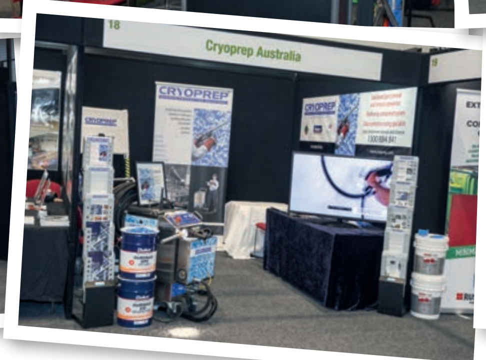




Denso

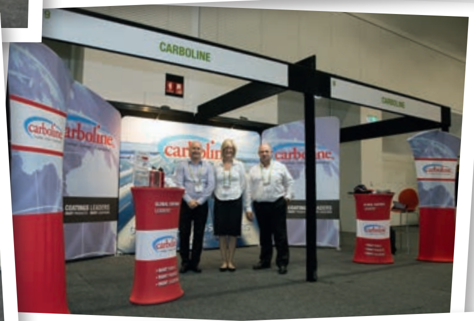

galvanizers
Hot Dip

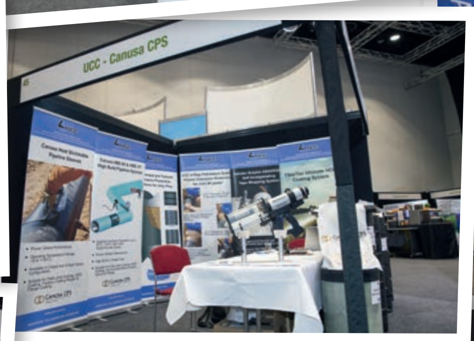
CORROSION & PREVENTION 2015 EXHIBITORS

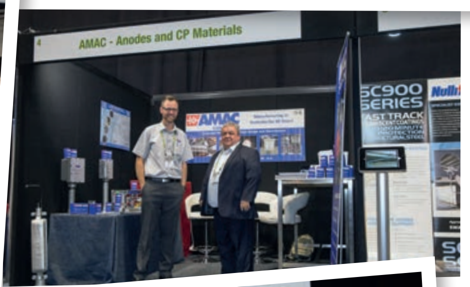


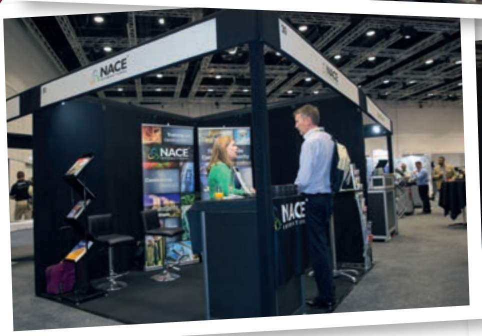
EXHIBITORS

CORROSION & PREVENTION 2015 EXHIBITORS









EXHIBITORS

CORROSION & PREVENTION 2015 EXHIBITORS

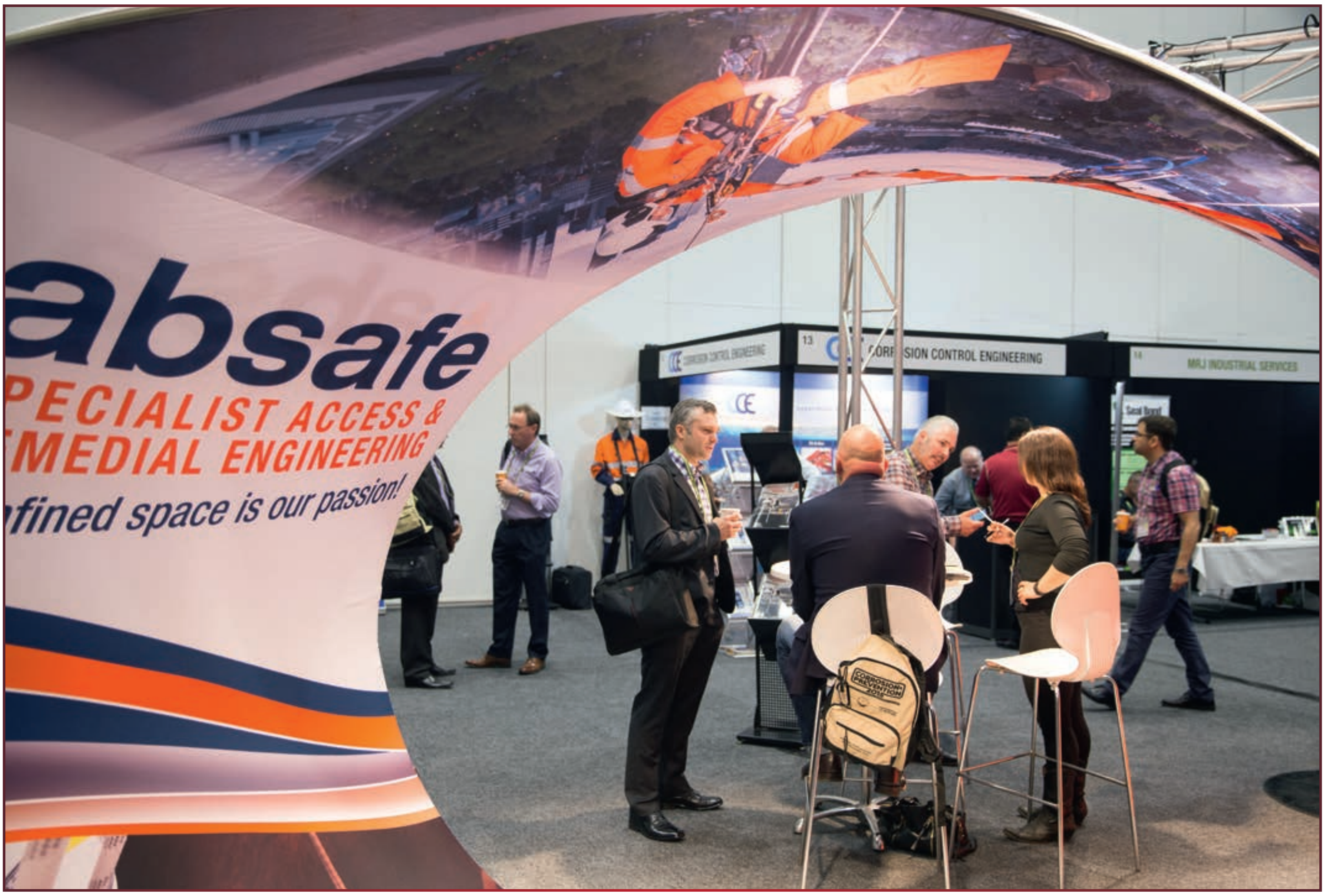
EXHIBITORS

CORROSION & PREVENTION 2015

EXHIBITORS

EXHIBITORS

BEST BOOTH AWARD



Absafe Pty Ltd is a leading specialist contractor that provides industrial rope access inspection, remedial and maintenance services to all forms of facade and structures as well as height safety services.

They specialise in working at height, confined spaces and other difficult access situations such as remote or rugged terrain. They are members of the Industrial Rope Access Trades Association, Australian Concrete Repair Association and Civil Contractors Federation as well as the Australian Corrosion Association.

Absafe has a proven history of projects within the industrial sector such as chimney stacks, cement silos, cooling towers, power station boiler ducts, transmission towers etc.

They are also highly experienced in bridge and façade inspection and refurbishment.

Absafe's core expertise lies in its ability to access difficult work spaces and carry out works proficiently and safely. Their long history combined with their constant striving to be at the forefront of the industry means that they bring a wealth of experience and equipment to their projects.

Their rope access skills and sound rigging expertise combined with a vast array of modern tools and equipment means they can cater for most emergencies.

Started in 2015, they now have a full specialist safety equipment retail business which operates out of their Gipps street, Collingwood, Melbourne office, or can be purchased online at www.shop.absafe.com.au

Andy Caddy – Director of Absafe receiving the Award.

TESTIMONIAL

FIRST TIME CONFERENCE ATTENDEE TESTIMONIAL

As a first-time attendee, at the time of submitting my delegate's registration form for the Corrosion & Prevention Conference in Adelaide, I was not exactly sure how it would benefit me and the business I am representing.

I was very glad, when after registration I received an invitation to the First-time Delegates Function before the official Welcome Reception. Attending that was an ice-breaking experience where I had the opportunity to meet, greet and chat to other 'first-timers' as well as colleagues that have been part of Corrosion & Prevention in the previous years. It was a great start!

Over the next three days I attended a number of very interesting presentations, discussions, forums, plenaries and (who doesn't love them) case studies. I was also privileged to witness the starting of Ed Potter Corrosion Clock. Moreover, I greatly enjoyed the variety of presented subjects, from those smoothly absorbable by my brain, to those mind-blowing researches and discoveries that only assured me that the corrosion world still has an abundance in store for me to learn.


Jan Sikora

The Adelaide Conference also made an outstanding contribution to my collection of business cards, but most importantly, gave me the opportunity to be acquainted with people within the industry who were willing to share their professional knowledge and experiences without any commercial barriers.

Altogether, those 4 days in Adelaide suited my expectations perfectly and from an unknown, it happened to be a fantastic educational and networking experience, resulting also in a bunch of notes and scribbles in my top drawer, always easy to reach and refer to.

Thanks to ACA for hosting such an excellent event and I am looking forward to attending another one at the next opportunity.

AWARDS

Each year a series of ACA Awards are announced and presented to successful recipients during the Annual Awards Dinner at the annual ACA conference – Corrosion & Prevention.

The ACA awards papers of outstanding quality presented at a conference, seminar or symposium held under the auspices of the ACA, or published in the ACA's publication *Corrosion & Materials*. These papers are judged by the ACA Awards Committee comprised of Les Boulton, Bruce Hinton and Erwin Gamboa.

The ACA also recognises members for outstanding services to the Association through Life Membership and services to the industry through other prestigious awards.

AC Kennett Award

The AC Kennett Award is awarded each year to the best paper presented under the auspices of the Association that deals with non-metallic corrosion. The recipient also receives a cheque for $1,500. The receipt of the AC Kennett Award was **Tony Wells** for the paper, '*Findings of a 4 Year Study of Concrete Sewer Pipe Corrosion*', co-authored by Rob Melchers. Tony Wells was unable to attend the conference, so Robert Melchers accepted the award on his behalf.

SUMMARY: Microbial induced corrosion (MIC) of reinforced concrete sewer piping and manholes is a significant issue in Australia and overseas costing water authorities hundreds of millions of dollars annually. It is anticipated that as the country's sewer infrastructure ages the problem will become more severe. Over the last 4 years an ARC and industry funded research project has been undertaken with the aim of building a mathematical model to predict the corrosion of concrete as a function of exposure time and environmental and operational conditions. After almost 4 years of field trials in Sydney, Melbourne and Perth sewers, a detailed understanding of the evolution of the corrosion process has emerged and a phenomenological model has been developed. The paper described the study findings and their implication for pipe service life prediction.

Best Papers

In pursuit of attracting quality technical papers, the ACA annually awards two certificates of merit for papers either published in *Corrosion & Materials* or presented at the annual conference. The award will be made only where the standard of papers is of a level warranting recognition; one certificate is for the best review paper and the other is for the best research paper.

Marshall Fordham Best Research Paper Award

The Marshall Fordham Best Research Paper Award was presented to **Thunyaluk (Kod) Pojtanabuntoeng** for the paper '*New Experimental Rig to Investigate Corrosion under Insulation at Different Climate Conditions*' co-authors Laura Machuca, Mobin Salasi, Brian Kinsella and Martin Cooper, presented at Corrosion & Prevention 2014 in Darwin.

SUMMARY: Corrosion under insulation (CUI) has been one of the major causes of failure in the oil and gas industry. In most cases, progress of corrosion under the insulation is detected during routine maintenance and inspection. However in a few situations CUI is only detected after a failure and a significant loss of containment has occurred. Prediction and detection of CUI are two major challenges confronting oil and gas operators. From the scientific standpoint, this topic lacks comprehensive academic research.

Essentially, there are different classes of laboratory test methods identified in the literature for investigating corrosion under insulation and these involve: a) accelerated CUI testing, b) ASTM test rig, and c) rain chamber. This paper outlined limitations and advantages of the available test rigs. The aim of this project was to develop a test rig which can improve the understanding of CUI and determine the contributing factors and find out possible ways of reducing the rate of CUI. Preliminary data employing the new test rig was presented and discussed.

David Whitby Best Review Paper Award

The David Whitby Best Review Paper Award was presented to **Laura Machuca** for the paper '*Microbiologically Influenced Corrosion: A Review Focused On Hydrotest Fluids in Subsea Pipelines,*' that was presented at Corrosion & Prevention 2014 in Darwin.

SUMMARY: The selection of an appropriate seawater treatment for preservation of subsea pipelines during hydrotesting and subsequent wet lay-up poses a significant dilemma for offshore engineers. Seawater, which is routinely used in the hydrotesting of offshore pipelines, contains oxygen and microorganisms which are known aggressive species towards metallic materials. Particularly, microbiologically influenced corrosion (MIC) represents a serious threat to the extended preservation of wet-parked pipelines where degradation of treatment chemicals and the increase in microbial activity are expected. Despite the best efforts of corrosion researchers, mechanistic aspects of MIC in wet-parked pipelines remain elusive mainly because of the intricacies of biofilm-steel interactions and the diversity and variable nature of microbial life. In addition, there is limited experience and experimental data available on the long-term performance of hydrotest fluids and as a result, key misconceptions, biases and knowledge gaps continue to persist in the understanding and control of MIC in wet-parked assets. This article reviewed the literature on MIC of offshore pipeline steels in seawater, in particular, MIC associated with hydrotesting and wet parking of pipelines to appraise methods, challenges and advances in the field. The impact of physico-chemical parameters and substratum properties on microbes and biofilms are discussed in an attempt to provide an update on the critical factors influencing MIC.

LIFE MEMBERSHIP

Life Membership is awarded for outstanding service to the ACA over an extended period either to a Branch or the Council and is awarded only as agreed by Council. At Corrosion & Prevention 2015, four Life Memberships were awarded:

Peter Hart

Peter joined the ACA in the early 1970s and had the honour of holding the ACA's 'First' Coating Inspector's Certificate issued in the early 1980s. Has served his local branch as Secretary, Membership Officer, Treasurer and Branch President and provided significant support to his local branch through a difficult time and contributed to the growth of the Association in South Australia.

Peter served as the president of the Blast Cleaning & Coating Association before it merged with the ACA.

In his career, Peter connected with the ACA while he was a paint sales representative for Taubmans Paints, and over the years progressed to General Manager. In 1997 he joined Incospec & Associates as a Director.

Brian Hickinbottom

Brian joined the ACA in 1972. He was an ACA Trainer in the 1990's, served as a committee member of both the Western Australia and New South Wales Branches and was ACA President in 1990-1991.

Brian represented Australia as a delegate to the International Corrosion Congress, was a member of the Organising Committee for International Corrosion Congress in Melbourne 1996 and currently serves the ACA on the C&P Technical Committee.

Brian commenced his working life in 1946 as an apprentice tool maker with CC Engineering. Throughout his career he worked for Hudson and West, as a Design Engineer and also managed a cement plant in Fiji for Fiji Industries. He worked at BHP for over 20 years in a variety of engineering roles including construction, mining, commissioning and maintenance.

John Grapiglia

John has served the ACA in the position of President in 2004 and made a significant contribution as Chairman of Operations Committee from 2008 – 2011. He has also spent many years as an active member of his local Branch Committee in Western Australia.

John graduated as an Electronics Engineer in 1980 from the Royal Melbourne Institute of Technology (RMIT) and started work for what was then Telecom in cable protection. Throughout his career he has been involved in a variety of cathodic protection projects, ranging from onshore pipelines and structures, reinforced concrete structures, and offshore projects. He is currently a Principal Engineer and Company Director for Corrosion Control Engineering (WA) Pty Ltd.

Graham Sussex

Graham has served the ACA on the committee of his local Branch including the roles of President and Technical Director. He also provided a significant contribution in the role of editor of Corrosion Australasia (1989 -1995). He was the Convenor for the Technical Committee for 13th International Corrosion Congress in 1996 and the ACA's 41st annual conference in 2003.

Across two decades Graham was the Convenor of WTIA ACA joint panel 11 on Welding and Corrosion from 1993-1996 and 2000-2003 and he currently serves as a member of the Australian Standards Committee revising - AS1554.6. Graham also supports kindred organisations as the Technical Specialist for the ASSDA and the Nickel Institute.

Graham has over 35 years hands-on consulting and research experience in the UK and Australia including, Technical Director and then CEO of the Institute of Materials Engineering Australasia, Principal Consultant with ETRS and Project Officer, Corrosion and Protection Centre Industrial Services, University of Manchester, United Kingdom. Since January 2001. He is the Director and Corrosion/Materials Consultant at Sussex Materials Solutions.

PARTNER PROGRAM

The ACA developed a delightful program of locally inspired activities for the C&P2015 Partner Program. The 3 day activity program included a visit to the Adelaide Zoo to see the only pair of breeding Giant Pandas in the Southern Hemisphere! A tour of Haigh's Chocolates, a visit to Hanhdorf and high tea at Udder delights with the highlight being the Penfolds Magill Estate Wine Tour, Tasting & Lunch.

Partner Program Testimonial

It was an absolute pleasure to be the local leader for the Partner Program, and what a lovely bunch of ladies! Participants came from far and wide – USA, NZ, Tasmania, Victoria, NSW, WA, and a local 'part timer'.

The ACA put together an excellent program which offered something for everyone and showcased a little taste of Adelaide. The highlights for everyone were the guided tour of the Adelaide Zoo and the visit to Penfolds.

The first day of the program, being Monday, was an early start and we were off for the short trip to the Zoo. On this day we were joined by another partner and her two teenage girls who were incredibly excited to see the 'giant' pandas. For many in the group, it was their first opportunity to see pandas and Wang Wang (male) and Funi (female, possibly expecting a cub) certainly put on a show. They were rather active, especially Wang Wang and also lounged back eating, of course! Prior to seeing the pandas, we all cooed over the red 'lesser' pandas who came down from their trees one at a time for breakfast – the male, followed by two younger males, the mother staying high in the tree. Monday is the day they are given a special milk preparation with vitamins, and they also enjoyed pieces of fruit which they ate rather daintily. Following their fill, one at a time, they went back up into their trees. After morning tea, complete with panda faces in the froth of our coffee, we went for a guided hike around the Zoo. Although starting to warm up, the canopy of trees made for a most enjoyable morning.

Back to the Adelaide Convention Centre for lunch and then on to Haigh's, the well-known Adelaide maker of fine chocolate, who have recently celebrated their 100th birthday. We learnt of the company history, the various family members and then of the making of the chocolate, which starts with the cacao pod. We saw many members of staff at work including two men rolling balls of mixture by hand, and weighing them, for the production of Christmas pudding chocolates. Although we tasted some samples, there was plenty of time to wander around the shop to purchase and the majority of participants departed carrying a bag!

A more leisurely start the next day and off to the Penfolds Magill Estate, home of the famous Grange wine, situated in the Adelaide foothills. Included, was a visit to Grange cottage built in the 1840s. It is not generally open for viewing, so we were privileged to wander around inside. It was as though the occupants had just left! With my interest in history and family history, this was a wonderful opportunity to see how our early ancestors in Adelaide lived. The company started with Dr Christopher and Mary Penfold. After her husband's early death, Mary truly built up the company together with her daughter and son-in-law. Originally the property consisted of 500 acres, but now is only 12. We then enjoyed a fascinating walk amongst the historical workings of the winery and saw many barrels stored in the tunnels. This was followed by a lengthy wine tasting and lunch. As we ladies know, the lunch was superb, albeit drawn out! Fortunately we had a spare spot and Thomas our fantastic bus driver also enjoyed some lunch!

Our final day was a scenic drive up in the hills to Hahndorf, Australia's oldest inhabited German village. Thomas made a brief stop at Beerenberg, for their famous jams, and then a stroll along the main street of Hahndorf for a lovely high tea at Udder Delights, where we feasted on homemade cheese and other locally produced delights.

All in all, an excellent program which the ladies enjoyed very much.

Sandra Twining
sandra.twining@tcorr.com.au

ACA Conference Attendance Scholarship Recipients

The ACA Foundation was delighted to award five scholarships to enable individuals to attend and participate in Corrosion & Prevention 2015. The scholarships target Post Graduate Students and individuals who have not previously attended a Corrosion & Prevention conference. Conference Attendance Scholarships were awarded to:

Post Graduate Conference Attendance Scholarship

- **Amy Spark**

First Time Conference Attendance Scholarship

- **Tom Sullivan**, SA Water
- **Andrew Marinkovic**, Vinsi Partners
- **Matthew Duncanson**, SMEC
- **Huw Dent**, GPA Engineering

The recipients were all extremely grateful for their scholarships and the opportunity to participate in Corrosion & Prevention 2015. In their post-conference reports the recipients nominated the following conference highlights.

One of the things that stood out to **Andrew Marinkovic** was, "*I was excited to see so much knowledge shared in one room with such enthusiasm, it was eye opening. Everyone I spoke to (including exhibitors, ACA staff and delegates) were very approachable and keen for a good conversation about corrosion.*"

Tom Sullivan indicated that he, "*found the asset management stream of the conference the most beneficial as I have been working in the area of asset management at SA Water in the Civil Engineering field.*" Recipients reported many other program highlights, including the following paper highlights from **Huw Dent**.

- *Robert Melcher's paper titled "Internal Corrosion of Parked Steel Oil Pipelines" identifying the potential for under deposit corrosion in mothballed or hydrotested pipelines; reinforcing the need to use well filtered hydrotesting fluids and controlled mothballing strategies;*
- *Ian MacLeod's enthusiastic demonstration of a horizontally driven steam engine whilst presenting his paper "Corrosion of Iron Steamships"; and*
- *Robert Francis' PF Thompson Lecture reviewing the historical works of famous scientists responsible for the galvanic series used today, culminating in corrosion powered rendition of Smoke on the Water.*

While **Tom Sullivan** also thought that the "*plenary sessions by prominent speakers were another highlight of the conference for me. The plenary sessions varied greatly in terms of information covered however the one I most enjoyed was "3D Visualisation of Reinforcement Corrosion within Concrete Marine Structures". This session showed that it was not only permeability but capillary action of the concrete that effected time for delamination or spalling to occur, particularly in a wet-dry environment.*"

Social Program

In regards to the Social Program, **Amy Spark** commented that, "*from a more social perspective, the Young Corrosion Group event was a great night with much fun had by all and the Awards dinner was another massive success. While the entertainment was rather confusing to begin with once we clued in it was great and the DJ was highly entertaining and spun some great dancing tracks.*"

While **Tom Sullivan** thought that the, "*First Time Delegates Function was a great way to meet new people and make networking throughout the conference easier.* "

Amy Spark

Tom Sullivan

Andrew Marinkovic

Matthew Duncanson

Benefits of attending

Andrew Marinkovic thought that the conference provided a "great opportunity to network, meeting other young professionals like myself who shared similar experiences and more senior professionals who have been in the industry for decades."

Amy Spark commented on another benefit of attending the conference, *"As I come to the end of my PhD studies, this was a great chance to learn what different companies are working in corrosion and what roles they play in the fight against corrosion. It gave me some new ideas about what the possibilities are when I finish my PhD as well as giving me some interesting new research avenues to follow."*

In conclusion

All the Scholarship receipts were extremely grateful for the conference attendance opportunity, along with thanking the Foundation and its donors for the scholarship, **Andrew Marinkovic** also thanked *"the sponsors who hosted each of the (social) events for their generous support of the events."*

Finally, some advice from **Huw Dent** for potential Corrosion & Prevention 2016 delegates, *"For those of you considering whether the conference is worthwhile, I recommend you attend next year. I thought it was invaluable to my development as an engineer and I hope to see you there next year."*

Huw Dent

Foundation Announces another Two Scholarship Recipients at ACA Annual Awards Dinner

In his last official capacity as Chair of the ACA Foundation, Dean Wall announced the recipients of the ACA Foundation International Conference Scholarships. The purpose of this scholarship is to support the recipient to attend and participate in an international conference. The recipients were;

- **Mieka Webb**, Department of State Development, SA and;
- **Vahid Afshari**, GHD

The scholarship provides each recipient with $3,500 to assist with the cost of attending an international conference. The scholarship can be used to cover the cost of conference registration, airfares and accommodation.

Both recipients have elected to use the scholarship to attend NACE's Corrosion 2016 conference that will be held in Canada in March.

On behalf of all its 2015 Scholarship recipients, the ACA Foundation would like to thank all the Foundation Centurions and Donors, who without their generous and ongoing support all this would not be possible.

Mieka Webb receives her award.

Vahid Afshari receives his award.

Dean Wall announcing the recipients.

ACA Standards Update

Welcome to the first corrosion related standards report for 2016.
The standards reporting for 2016 is scheduled against Technical Groups (TG) as indicated below:

Issue	2016 Standards search for TG interests	Issue	2016 Standards search for TG interests
Feb	Concrete Structures & Buildings; Asset Management	Aug	Oil & Gas; Mining; Refining & Processing
May	Coatings	Nov	Cathodic Protection; Water & Waste Water

This Standards report focuses on the **Concrete Structures & Buildings TG** and **Asset Management** relating to corrosion.

As previously this is in two stages, namely:

Stage 1

A global standards and publication focus at **12 January 2016**, searching through SAIGLOBAL Publications at https://infostore.saiglobal.com/store, for all current publications and standards relating to the ACA Technical Groups, with this editions group focus being the '**Concrete Structures & Buildings**' Technical Group. This stage will include a section on Asset Management as it relates to corrosion and its prevention.

These results are shown in Tables 1 & 2.

Stage 2

A SAI Global search, as previously, at http://www.saiglobal.com/online/ for new standards, amendments or drafts for AS, AS/NZS, EN, ANSI, ASTM, BSI, DIN, ETSI, JSA, NSAI and standards and amendments for ISO & IEC published from **21 October 2015 - 12 January 2016**, using the key words and key word groups:

- "durability'.
- "corrosion' or 'corrosivity' or 'corrosive'; but not 'anodizing' or 'anodize(d)'.
- "paint' or 'coating'; but not 'anodizing' or 'anodize(d)'.
- "galvanize' or 'galvanized' or galvanizing'.
- "electrochemical' or 'electrolysis' or 'electroplated'.
- "cathode' or 'cathodic'.
- "anode' or 'anodic'.
- "corrosion' and 'concrete' or 'concrete' and 'coatings'.

These results are shown in Table 3.

Summary

Stage 1 Report

Through SAIGLOBAL Publications at https://infostore.saiglobal.com/store there were for a search on:

a. 'Concrete and Corrosion', there were 168 publications (up 4 from last year) with no Australian Standards but one BRANZ publication "BRANZ Bulletin 464 Preventing Corrosion of Reinforcing Steel in Concrete". See Table 1.

b. 'Asset Management'; there were 154 publications with 4 from AS/NZS relating to practices and 4 from various publishers relating to the Construction Industry. See Table 2.

c. 'Asset Management and Corrosion'; there were no publications relating to this search.

d. API 571 'Damage Mechanisms Affecting Fixed Equipment in the Refining Industry'; this code is featured because of the large amount of Corrosion Under Insulation (CUI) found to be present across Australasia an example of CUI is shown below.

Top photo is with insulation removal; bottom photo is after cleaning. The support bracket is an insulation intrusion allowing moisture ingress allowing a travel path along the bracket to vessel interface.

API 571 Section 4.3.3 Corrosion under Insulation (CUI) details;

i. Affected materials.
ii. Critical factors.
iii. Affected units and equipment.
iv. Examples of where CUI can occur.
v. Appearance or Morphology of Damage.
vi. Prevention/Mitigation.
vii. Inspection and monitoring.

Stage 2 Report
Across SAIGLOBAL online Standards Publications there was a total of 42 listings of new Standards, Drafts and Amendments, found issued from 21 October 2015 - 12 January 2016; 0 from AS/NZS. These results are shown in 3 below.

Regards
ACA – Standards Officer - Arthur.Austin@alsglobal.com

Stage 1 Report
Stage 1 Report on SAIGLOBAL Publications at https://infostore.saiglobal.com/store, for all current publications and standards relating to "Concrete Structures & Buildings" Technical Group.

Table 1
For Titles search on https://infostore.saiglobal.com/store on 12 January 2016 for 'concrete and corrosion' for the 'Concrete Structures and Buildings' TG there were 168 citations, none from AS/ASNZS but 1 from BRANZ, 'BRANZ Bulletin 464 Preventing Corrosion of Reinforcing Steel in Concrete'; there were no new publications since this time last year.

There was 9 ASTM, 4 American Concrete Institute and 7 NACE publications, as shown below.

ASTM	American Concrete Institute	NACE
ASTM STP1065-90 Corrosion Rates Of Steel In Concrete	ACI 222.3R:2011 Guide To Design And Construction Practices To Mitigate Corrosion Of Reinforcement In Concrete Structures	NACE 01110:2010 Stray-Current-Induced Corrosion In Reinforced And Prestressed Concrete Structures
ASTM STP1276-96 Techniques To Assess The Corrosion Activity Of Steel Reinforced Concrete Structures	ACI 222R:2001 (R2010) Protection Of Metals In Concrete Against Corrosion	NACE 05107:2007 Report On Corrosion Probes In Soil Or Concrete
ASTM STP629-77 Chloride Corrosion Of Steel In Concrete	ACI SP 291 CD:2013 Corrosion Of Reinforcing Steel In Concrete - Future Direction: Proceedings - Hope & Schupack Corrosion Symposium CD	NACE SP 01 12:2012 Corrosion Management Of Atmospherically Exposed Reinforced Concrete Structures
ASTM STP713-80 Corrosion Of Reinforcing Steel In Concrete	ACI C 25:1993 Concrete Durability: Corrosion Protection	NACE SP 01 87:2008 Design Considerations For Corrosion Control Of Reinforcing Steel In Concrete
ASTM STP818-83 Corrosion Of Metals In Association With Concrete		NACE SP 03 08:2008 Inspection Methods For Corrosion Evaluation Of Conventionally Reinforced Concrete Structures
ASTM STP906-86 Corrosion Effect Of Stray Currents And The Techniques For Evaluating Corrosion Of Rebars In Concrete		NACE SP 03 90:2009 Maintenance And Rehabilitation Considerations For Corrosion Control Of Atmospherically Exposed Existing Steel-reinforced Concrete Structures
ASTM C1582/C1582M-11 Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete		NACE SP 01 00:2014 Cathodic Protection To Control External Corrosion Of Concrete Pressure Pipelines And Mortar-Coated Steel Pipelines For Water Or Waste Water Service
ASTM G109-07(2013) Standard Test Method for Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments		
ASTM G180-13 Standard Test Method for Corrosion Inhibiting Admixtures for Steel in Concrete by Polarization Resistance in Cementitious Slurries		
NOTE: Highlighted publications relate to Asset Management		

Table 2 – For Titles search on https://infostore.saiglobal.com/store on 12 January 2016 for 'Asset Management'; there were 154 publications with 4 from AS/NZS relating to practices and 4 from various publishers relating to the Construction Industry.	
AS ISO 55001:2014	Asset management - Management systems - Requirements
AS ISO 55002:2014	Asset management - Management systems - Guidelines for the application of AS ISO 55001
AS/NZS ISO/IEC 19770.1:2007	Information technology - Software asset management - Processes
AS ISO 55000:2014	Asset management - Overview, principles and terminology
PAS 1192-3:2014	Specification For Information Management For The Operational Phase Of Assets Using Building Information Modelling
PAS 1192-5:2015	Specification For Security-Minded Building Information Modelling, Digital Built Environments And Smart Asset Management
SR CWA 16633:2013	Ageing Behaviour of Structural Components With Regard to Integrated Lifetime Assessment and Subsequent Asset Management of Constructed Facilities
NEN CWA 16633:2013	Ageing Behaviour Of Structural Components With Regard To Integrated Lifetime Assessment And Subsequent Asset Management Of Constructed Facilities DIN CWA 16633*DIN SPEC 91298 (2013-09)

Stage 2 Report

Table 3 – Standards for AS, AS/NZS, EN, ANSI, ASTM, BSI, DIN, ETSI, JSA, NSAI and Standards and Amendments for ISO & IEC PUBLISHED from 21 October 2015 - 12 January 2016 for:	
New standards, amendments or drafts for AS, AS/NZS, EN, ANSI, ASTM, BSI, DIN, ETSI, JSA, NSAI and Standards or Amendments for ISO & IEC PUBLISHED between 21 October 2015 - 12 January 2016	
Key word search on 'durability'- 4 citations with 1 corrosion related citations found; 1 ISO Standards was found for testing of full-flow lubricating oil filters for combustion engines (ISO/FDIS 4548-14).	
ISO 19862:2015	Buildings and civil engineering works - Sealants - Durability to extension compression cycling under accelerated weathering
Key word search on 'corrosion' or 'corrosivity' or 'corrosive'; but not 'anodizing' or 'anodize(d)'- 8 citations found; 0 from AS/NZS	
ISO 18070:2015	Corrosion of metals and alloys - Crevice corrosion formers with disc springs for flat specimens or tubes made from stainless steel
ISO 18089:2015	Corrosion of metals and alloys - Determination of the critical crevice temperature (CCT) for stainless steels under potentiostatic control
ISO 21207:2015	Corrosion tests in artificial atmospheres - Accelerated corrosion tests involving alternate exposure to corrosion-promoting gases, neutral salt-spray and drying
ISO 28706-4:2016	Vitreous and porcelain enamels - Determination of resistance to chemical corrosion - Part 4: Determination of resistance to chemical corrosion by alkaline liquids using a cylindrical vessel
ISO 3160-2:2015	Watch-cases and accessories - Gold alloy coverings - Part 2: Determination of fineness, thickness, corrosion resistance and adhesion
ISO/DIS 15741	Paints and varnishes - Friction-reduction coatings for the interior of on- and offshore steel pipelines for non-corrosive gases
DIN 65342 (2015-12)	Aerospace series - Anchor nuts with MJ thread, deep counterbore, self-locking, two lug, reduced, corrosion-resisting steel, classification: 1 100 MPa/315 øC/425 øC; Text in German and English
DIN EN ISO 8044 (2015-12)	Corrosion of metals and alloys - Basic terms and definitions (ISO 8044:2015); Trilingual version EN ISO 8044:2015
Key word search on 'paint' and or 'coating'; but not 'anodizing' or 'anodize(d)' or corrosion– 33 Publications found; 0 for AS AS/NZS	
ISO/TS 19397:2015	Determination of the film thickness of coatings using an ultrasonic gage
ISO/FDIS 21809-3	Petroleum and natural gas industries - External coatings for buried or submerged pipelines used in pipeline transportation systems - Part 3: Field joint coatings
DIN EN ISO 10309 (2015-11) (Draft)	Metallic coatings - Porosity tests - Ferroxyl test (ISO 10309:1994); German and English version FprEN ISO 10309:2015
DIN EN ISO 14604 (2015-11) (Draft)	Fine ceramics (advanced ceramics, advanced technical ceramics) - Methods of test for ceramic coatings - Determination of fracture strain (ISO 14604:2012); German and English version FprEN ISO 14604:2015

DIN EN ISO 14647 (2015-11) (Draft)	Metallic coatings - Determination of porosity in gold coatings on metal substrates - Nitric acid vapour test (ISO 14647:2000); German and English version FprEN ISO 14647:2015
DIN EN ISO 15730 (2015-11) (Draft)	Metallic and other inorganic coatings - Electropolishing as a means of smoothing and passivating stainless steel (ISO 15730:2000); German and English version FprEN ISO 15730:2015
DIN EN ISO 16961 (2015-12)	Petroleum, petrochemicals and natural gas industries - Internal coating and lining of steel storage tanks (ISO 16961:2015); English version EN ISO 16961:2015
DIN EN ISO 20502 (2015-11) (Draft)	Fine ceramics (advanced ceramics, advanced technical ceramics) - Determination of adhesion of ceramic coatings by scratch testing (ISO 20502:2005+Cor 1:2009); German and English version FprEN ISO 20502:2015
DIN EN ISO 26423 (2015-11) (Draft)	Fine ceramics (advanced ceramics, advanced technical ceramics) - Determination of coating thickness by crater-grinding method (ISO 26423:2009); German and English version FprEN ISO 26423:2015
DIN EN ISO 26424 (2015-11) (Draft)	Fine ceramics (advanced ceramics, advanced technical ceramics) - Determination of the abrasion resistance of coatings by a micro-scale abrasion test (ISO 26424:2008); German and English version FprEN ISO 26424:2015
QPL 53039 Revision Oct 2015	Qualified Product List Of Products Qualified Under Performance Specification - Mil-Dtl-53039 - Coating, Aliphatic Polyurethane, Single Component, Chemical Agent Resistant - Revision Oct 2015
QPL 64159 Revision Oct 2015	Qualified Product List Of Products Qualified Under Performance Specification - Mil-Dtl-64159 - Camouflage Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant - Revision Oct 2015
ISO/DIS 19403-1	Paints and varnishes - Wettability - Part 1: Terminology and general principles
ISO/DIS 19403-2	Paints and varnishes - Wettability - Part 2: Determination of the surface free energy of solid surfaces by measuring the contact angle
ISO/DIS 19403-3	Paints and varnishes - Wettability - Part 3: Determination of the surface tension of liquids using the pendant drop method
ISO/DIS 19403-4	Paints and varnishes - Wettability - Part 4: Determination of the polar and dispersive fractions of the surface tension of liquids from an interfacial tension
ISO/DIS 19403-5	Paints and varnishes - Wettability - Part 5: Determination of the polar and dispersive fractions of the surface tension of liquids from contact angles measurements on a solid with only a disperse contribution to its surface energy
SO/DIS 19403- I6	Paints and varnishes - Wettability - Part 6: Measurement of dynamic contact angle
ISO/DIS 19403-7	Paints and varnishes - Wettability - Part 7: Measurement of the contact angle on a tilt stage (roll-off angle)
ISO/FDIS 4629-1	Binders for paints and varnishes - Determination of hydroxyl value - Part 1: Titrimetric method without using a catalyst
ISO/FDIS 4629-2	Binders for paints and varnishes - Determination of hydroxyl value - Part 2: Method using a catalyst
DIN EN ISO 16482-1 (2015-11) (Draft)	Binders for paints and varnishes - Determination of the non-volatile-matter content of aqueous rosin-resin dispersions - Part 1: Oven method (ISO 16482-1:2013); German and English version FprEN ISO 16482-1:2015
DIN EN ISO 16482-2 (2015-11) (Draft)	Binders for paints and varnishes - Determination of the non-volatile-matter content of aqueous rosin-resin dispersions - Part 2: Microwave method (ISO 16482-2:2013); German and English version FprEN ISO 16482-2:2015
Key word search on 'galvanize' or 'galvanized' or galvanizing' – 0 citations found.	
Key word search on 'corrosion' and 'concrete' or 'concrete' and 'coatings' – 0 Standard Publications found.	
Key word search on 'cathode' or 'cathodic' – no corrosion related standards found.	
Key word search on 'anode' or 'anodes' or 'anodic' – 1 Standard Publications found.	
DIN EN 12438 (2015-12) (Draft)	Magnesium and magnesium alloys - Magnesium alloys for cast anodes; German and English version prEN 12438:2015
Keyword Search on 'electrochemical' or 'electrolysis' or 'electroplated' - 1 Standard Publications found, none from AA or AS/NZS.	
JIS G 3313:2015	Electrolytic zinc-coated steel sheet and strip
Keyword Search on 'anodize' or 'anodized' - 0 Publications found	

Eptec Group

Q: In what year was your company established?

A: Eptec was established in 1997 when the founder, Enrico Piccioli, left his role as a Director of Transfield to set up his own business

Q: How many employees did you employ when you first started the business?

A: At this time, Eptec employed the grand total of 3.

Q: How many do you currently employ?

A: The Eptec Group now employs, on average, 250 employees.

Q: Do you operate from a number of locations in Australia?

A: The Eptec Group has had a National presence since 1998 when it commenced services in WA. The business currently has permanent offices in NSW, Victoria and WA with plans to expand further in 2016.

Q: What is your core business? (e.g. blasting and painting, rubber lining, waterjetting, laminating, insulation, flooring etc.)

A: Eptec's core business is the Preservation and Rehabilitation of Assets. We have developed the full range of capabilities to meet the requirements of asset owners, irrespective of whether we are dealing with steel, concrete or GRE/GRP structures. Blasting & Painting and Concrete Remediation are the typical services provided but we have a broad engineering capability to address most forms of asset degradation.

Q: What markets do you cover with your products or services? eg: oil & gas, marine, chemical process, general fabrication, tank lining, offshore etc.

A: Eptec services all sectors with particular expertise in the Marine sector (Naval and Commercial Shipping) and Infrastructure such as bridges (road & rail), tunnels (road, rail, water, sewage) and water and sewage treatment plants. Our expertise is however, in our ability to preserve and protect assets and includes a diverse range of structures from Windfarms to Luxury apartments.

Q: Is the business yard based, site based or both?

A: We are a site operator and have built a flexible, multiskilled workforce designed to rapidly mobilise anywhere in Australia. Indeed, some of our most interesting work has been in the most remote parts of the country.

Ultimo bridge

HMAS Canberra

Q: What is your monthly capacity or tonnage that you can blast and prime?

A: We have never failed to meet a client's requirements and will rapidly scale to meet most demands.

Q: Do you offer any specialty services outside your core business? (eg. primary yard based but will do site touch up etc.)

A: We pride ourselves in our ability to find innovative solutions to most corrosion issues. Whether this is development of specialist equipment for Trenchbreakers or Sewer Pipe Lining, or underground soil consolidation structures using chemical injection, it is our ability to think outside the square which often brings the greatest benefits to our clients.

Q: What is the most satisfying project that you have completed in the past two years and why?

A: The most significant and satisfying recent project was the delivery of the 2 Australian Landing Helicopter Deck vessels for the Navy. The vessels were completed on time and budget. They are the newest, largest and most advanced Navy vessels in Australia. In terms of capability and technology, these amphibious assault ships represent a quantum leap for the Royal Australian Navy. They will also be able to conduct civilian-led humanitarian and disaster relief operations and non-combatant evacuations.

Q: What positive advice can you pass on to the Coatings Group from that satisfying project or job?

A: As with every job, fully understand the client's requirements both in terms of quality but also program and management of risk.

Q: Do you have an internal training scheme or do you outsource training for your employees?

A: We utilise both internal training as well as third party external training. The industry expects far greater capability from its contractors and internationally recognised qualifications and certifications such as NACE and PCCP are now our benchmark. These can only be achieved through structured external training sources. We are also working closely with equipment suppliers who frequently organise specific training on the latest equipment and products on the market. Our overriding aim is to ensure that we can offer our clients the most advanced and appropriate solution to meet their needs.

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EPTEC

Suzlon Windfarm

Spirit of Tasmania

GLNG Gas Transmission Pipeline

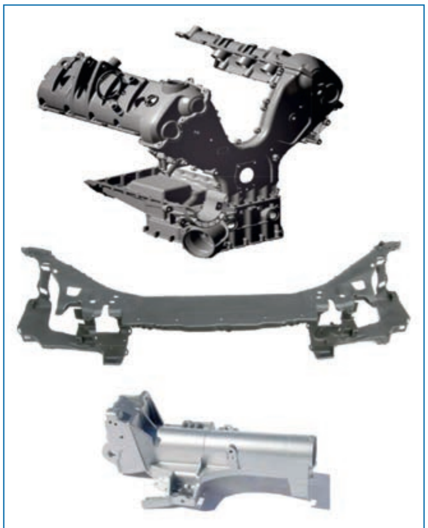
Corrosion in the 21st century... What's rusting?

MONASH University

Greetings fellow 'rust-busters'!! This month I have decided to forego the opportunity to have a University profile and images of our potentiostat collection gracing the pages of C&M. Instead, I have opted for an editorial piece which I think (hope) will better convey the life and times of a modern rust-buster in 2015, with a bit of view into the crystal ball.

There is no doubt that corrosion and corrosion control remain a critical topic as we move deeper into the 21st century. The global cost of corrosion when considering the sum of all the figures available from several nations, is in the vicinity of $US 1T… wait for it… per annum!

We live in a world of aging infrastructure, and a world that is amassing 'stuff', be it cars, boats, trinkets, or even that obligatory new phone each time a new model is released. What does this mean for a corrosion engineer in 2015, let alone in some years from now? Well, that is a very interesting question, the answer to which is pretty 'cool'. It means that there remain challenges, many more challenges than ever before. In fact, I believe there has never been a better time to be working in the area of corrosion… a statement I will attempt to qualify here.

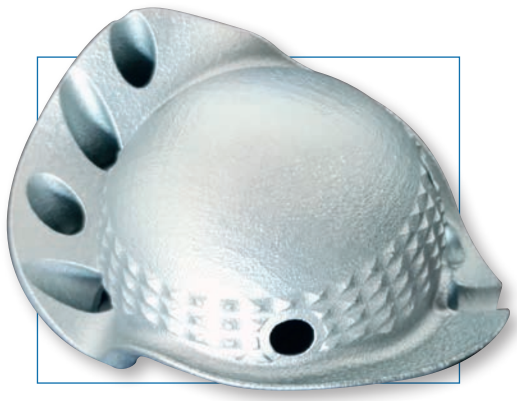


Examples of magnesium used in automotive applications including (top) Porsche engine covers and oil housing, (middle) Volvo instrument panel beam, and (bottom), Toyota steering column jacket.

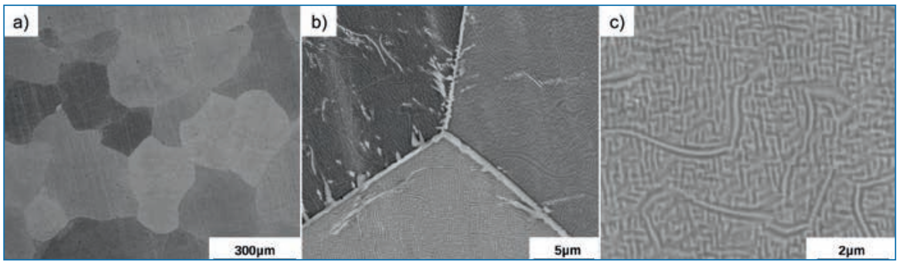
Source: Magontec GmbH and T.B. Abbott. Corrosion, Vol. 71, No. 2, (2015) pp. 120-127]

I am often asked similar questions (usually in the same conversation) by more traditional corrosion engineers. These questions are: *"Nick, why do your students work on such unusual topics? Is it true that some cant even use a potentiostat?"*, and *"Haven't you already solved this whole corrosion thing already?"* My response is that such questions (and thinking) are rather backward looking. Put simply, it is true that we presently don't have any (of the many) students at Monash working on traditional topics such as corrosion in chemical process industries or even corrosion of reinforced concrete (yes, the topic of my PhD!)… However I believe this is because we have — to a great extent — solved many such puzzles. Therefore, this begs the question as to what could one then possibly be working on with regards to corrosion if they aren't working of the problems of yester-year…?

To answer this question, we just need to look around us, and see how rapidly the world has changed in the past 5 years alone. Of the most obvious changes (and I can go on for many pages) we can identify at least the following. We all now have a smartphone or a laptop of which we want each new model to be lighter, stronger, and more durable (such devices need to be made of something). We all want lighter cars so we can spend less money on fuel (and simultaneously feel good about creating less pollution). In the unfortunate event of a broken bone, we would all love if we can be assured that a durable metal implant will save the day. We all want to fly to Europe faster, cheaper, and on a 'greener' plane that is more fuel-efficient yet damage tolerant. Governments are simultaneously legislating for less waste (read as a need for greater durability for the corrosion engineer), and imposing legislation that influences how engineers must behave. A couple of years ago, there was immense press when Ford (in the USA) transitioned towards an aluminium based vehicle, and similarly, there was great press last year when Porsche revealed its increased use of magnesium. In fact, many vehicles — perhaps even your own — have specific components produced by magnesium (see accompanying figure). In fact, the world production of aluminium and magnesium has increased dramatically (almost doubling in the last decade alone), meaning that understanding and controlling the durability of such light-metal based alloys, remains ultra critical… What do I mean by critical?… well… traditional approaches such as cathodic protection and / or Zn coatings (as applied to steels) don't work for aluminium and magnesium (I will spare you the technical details, but the already negative potentials and cathodic dissolution of light metals are among the reasons). The ol' play book is therefore… of little use. In a nutshell, materials we use are changing (for performance and legislation reasons) and we need to be ahead of the curve. To this end, a mini-army of PhD students at Monash are working on developing 'stainless light metals'. There is one cohort of students working on Al-alloys, and another working on Mg-alloys. Whilst these students may not realise it, they are the modern version of Harry Brearly, the English metallurgist who is credited with the invention of stainless steel in the early 1900s. The story of Harry Brearly is an interesting one, but I believe no more interesting than the contemporary story of the desire to produce stainless light alloys, and the innovative approaches being undertaken in the suburbs of Melbourne — often at odd times and often fuelled by caffeine alone.



3D printed acetabular cup, produced by selective laser melting of Ti-6Al-4V. This specific cup has been implant into a patient in Australia, produced at Monash University.



Microstructure of the high entropy alloy AlCoCrFeNi shown with increasing magnification from (a) to (c). The images are backscattered electron micrographs, revealing an ordered spaghetti structure on the nano-scale. Courtesy of PhD student Yao Qiu.

The light alloys example is just one, and there are many equally important examples of what is being researched as we speak. This includes studying corrosion in diverse (often extreme) environments. The example of the human body is a good one. How durable are titanium implants in the body? (see accompanying figure). Body fluid is salty, contains amino acids, and can stimulate surface films of calcium and phosphate… The situation is even more complex when seeking a resorbable (biodegradable) metal which is anticipated to degrade — aka corrode — in the body. In such cases, Mg- alloys are being studied as resorbable implants, and this is an example where corrosion could be beneficial and lead to better quality of life for the many stent requiring and orthopaedic patients around the world.

Speaking of modern innovations, the 3D printing of metals is undoubtedly going to be here to stay, with the advent of 'additive manufacturing' allowing tremendous developments such as bespoke components, minimised waste, on-demand production, and reduced production times as evidenced recently by the worlds first 3D printed jet engine (yes… also printed at Monash University). This begs the question… Do 3D printed components behave the same as conventional wrought components? Do they corrode faster, slower, at the same rate? (I wont answer that, but leave it for you to ponder!). The technical answer is that it comes down to the metallurgy and microstructure. A wrought component produced from casting, homogenising, hot rolling, perhaps solution treatment and cold rolling, may take weeks to complete its metallurgical processing route… however in 3D printing, the metallurgy is complete in a fraction of a second. That's right, in the time taken for a high-powered laser to blast and melt a small (several tens of microns) layer and move on to the next point, is all it takes. Enter a new metallurgical era… an era where the variety of alloys which can be made is not limited by ingot metallurgy and mutual solubility of metals. Indeed, from the variety of processes now available, for the first time ever, we can make ANY alloy we can dream up. To this end, I will leave you with one more example. Recently there has been much excitement surrounding a special class of alloys known as 'high entropy alloys'. Such alloys usually are made up from equi-atomic proportions of typically five metals, to produce some very unique properties (strengths, microstructures, and thermal stabilities). Yes, take any 5 metals, lets say… aluminium, cobalt, chromium, iron and nickel… add 20% of each… and what happens? Well, the astute reader will be laughing and perhaps will be thinking that aluminium melts at about 1200°C below the temperature where chromium may decide to melt, making a rather ugly alloy. That is correct if the alloy is attempted to made by ingot metallurgy and conventional casting (if even possible). However, such an alloy can be very readily 3D printed — the result is that the alloy produced has a complex microstructure, as shown in the accompanying figure. I show you this microstructure for a simple parting message. One can see that the microstructure is highly heterogeneous, which is classically considered very detrimental by the traditional corrosion engineer. Microstructural heterogeneity incites fear, for concentration gradients, solute depleted zones, and second phases all lead to micro-galvanic corrosion. This is conventional wisdom. However, much to our surprise, and delight, the heterogeneous microstructure in the high-entropy alloy shown is concomitant with a level of stainlessness far beyond that of stainless steel. Goodbye to conventional wisdom, and hello to trying to understand why such a microstructure can be one of the most corrosion resistant we have ever seen… Yes. There is much work left to be done. That work, and all the work described above, hinges on the highest level of characterisation and some of the worlds leading infrastructure. The work is tedious, expensive, and tiring, however, potentially revolutionising gas turbines engines, biomedical alloys, or creating more durable cars at half the weight, is worth the journey.

As such, next time you see a fresh faced kid claiming to be a corrosion engineer, yet on probing he/she is unable to use a potentiostat, remember they may able to code in augmented reality, able to turn your iphone into a rust seeking device or responsible for 3D printing your next implant, so cut them some slack. The future corrosion engineer will reflect diverse backgrounds and such individuals will have diverse skills. We need to embrace the variety of challenges ahead, and be ready with innovative solutions, fresh ideas, and fresh approaches. Lessons from the past will not be sufficient to prepare us for a rapidly transforming world, and thus we need to be ready to strap in for a fun ride ahead where 'stuff' will continue to corrode, but we just don't know exactly what that 'stuff' is yet…

By Nick Birbilis

Nick Birbilis is Professor and Head of the Department of Materials Science and Engineering at Monash University. He is a Fellow of NACE (National Association of Corrosion Engineers, USA) and a long time member of the ACA (formerly Victorian Branch President). He is handling editor for corrosion related manuscripts in Electrochimica Acta, and an Editorial board member for the journals Corrosion, Corrosion Reviews, and Corrosion Engineering, Science & Technology. Nick will complete his tenure as the Chair of the NACE Research Committee in 2016, a position he has held since 2013.

Nick Birbilis (top left) and the team of 23 rust-busters at Monash University. Students work on diverse topics including corrosion of next generation alloys and functional coatings, corrosion of 3D printed metals, corrosion modelling from first principles, corrosion in the human body, and the development of stainless light alloys.

Coatings Inspection Certificate

Up until 2005 The Australasian Corrosion Association Inc conducted a 5 day Coatings Inspection Certificate Course. It was designed to provide the requisite skills and knowledge to inspect protective coatings following the requirements of Australian/New Zealand Standards.

The list below contains the names of qualified ACA Coatings Inspectors who have satisfied the requirements to be issued with an ACA Coatings Inspection Certificate and who have 'refreshed' their certificate within the 5 year time frame required by the ACA Council. Some inspectors have cross – accredited to the internationally recognised NACE Coatings Inspection Program. In those cases, the validity of their ACA certification has been reconfirmed.

Every care has been take to ensure that at the time of publishing the information is correct. The Australasian Corrosion Association Inc does not accept any responsibility for any consequences which may arise from the use of this information. Those wanting to engage a Coatings Inspector should rely on their own judgement and if necessary seek other advice as to whether the person has suitable work experience and references for the type of work proposed.

No legal liability for negligence or otherwise can be accepted by The Australasian Corrosion Association Inc for the information or the use of the information contained in this listing.

If you have any queries please contact The Australasian Corrosion Association Incorporated directly on +61 3 9890-4833 or via email to aca@corrosion.com.au.

Please note: this list is current as at 16 January 2016.

ACA Coating Inspectors

Name	Cert. No.	Expiry Date
Gary Abbott	4080	31/12/2020
Richard Adams	1230	19/04/2015
Andrew Aidulis	1404	31/12/2020
Derek Allen	3870	31/12/2020
Kamran Armin	4232	28/02/2016
Peter Atkinson	3234	31/07/2015
Trevor Baensch	2211	31/12/2020
Travis Baensch	4209	12/08/2015
Stuart Bayliss	247	31/12/2018
Ben Biddle	1279	31/12/2020
Mark Blacklock	3501	2/07/2015
Michael Boardman	1051	31/12/2017
Jason Bourke	2597	31/12/2019
Matthew Boyle	1429	30/04/2016
Kingsley Brown	2603	31/10/2015
Sean Anthony Burke	3428	31/12/2018
Harold Burkett	361	28/02/2017
Elliot Burns	972	19/04/2015
Micah Butt	2397	31/10/2016
Luis Carro	2212	31/12/2017
Rod Cockle	1410	31/12/2020
John Cooke	3235	31/12/2018
Cameron Cooper	466	6/07/2016
Kerry Cooper	2483	31/12/2020
Dean Crase	4137	6/07/2016
Michael Crowley	4197	31/12/2017
David Daly	7343	31/12/2016
Cheryl Dalzell	3940	19/04/2015
Robert de Graaf	719	31/12/2017
Phill Dravitski	1593	31/12/2020
William Dunn	3386	31/12/2018
Ken Dunn	1296	6/07/2016
Steve Dyer	3879	31/12/2020
Nick Edwards	1992	31/12/2020
Dave Elder	155	31/12/2020
Todd Elkin	3402	31/12/2020
John Elomar	4204	19/04/2015
Tony Emery	4130	2/07/2015
Tony Evans	2086	6/07/2016
Wayne Ferguson	893	31/12/2017
Jerry Forslind	1129	31/12/2020
Phillip Foster	2254	31/12/2019
Rob Francis	720	31/12/2017
Robert Freedman	76	31/12/2017
Brett Gale	3774	12/08/2015
David Gates	2599	19/04/2015
Collin Gear	2623	31/12/2017
Robert Glover	1362	31/12/2017
Ian Glover	393	28/02/2015
Wayne Gray	3606	31/12/2019
Ray Grose	2956	31/12/2017
Jim Haig	394	12/08/2015
Brian Harris	1054	31/12/2018
Peter Hart	1	31/10/2015
Shane Hawker	7342	31/12/2016

Rohan Healy	3184	31/12/2017
Clayton Henry	1595	31/12/2017
Chris Heron	1619	31/05/2016
Don Herrigan	4033	31/12/2020
Anthony Heuthorst	2297	31/12/2019
Frank Hiron	2888	31/12/2018
Paul Hunter	2988	31/12/2017
Jeffrey Hurst	1746	31/12/2018
Gary Hussey	3984	2/07/2015
Clinton Iliffe	4034	31/12/2020
Basyl Jakimow	3230	31/12/2020
Robert Johnson	2625	31/12/2018
Matthew Johnson	2359	12/08/2015
Robert Johnson	3354	12/08/2015
Michael Johnstone	2964	31/12/2018
Roger Kearney	1121	31/12/2018
Graeme Kelly	721	31/12/2017
Leonard Kong	3538	31/12/2018
Joseph Kowal	553	31/12/2020
Narend Lal	3355	31/12/2019
Alan Lee	3539	31/12/2018
David Lepelaar	3356	31/12/2018
Neil Alan Lewis	2598	31/12/2018
Daniel Lillas	3597	30/11/2019
Peter Luke	3795	31/12/2019
Jonathan Mace	4035	6/07/2016
Alistair MacKenzie	4191	31/12/2017
Spencer Macsween	3170	31/12/2017

Willie Mandeno	1216	31/12/2017
Tony Mans	3233	31/12/2017
Bradley Marsh	3232	31/12/2020
Andrew Martin	545	31/12/2019
George Martin	669	2/07/2015
Garry Matthias	1481	30/04/2016
Peter McCormack	4353	31/12/2017
David McCormack	4352	6/07/2016
Brett Meredith	2218	30/11/2015
John Mitchell	1042	31/12/2017
Wayne Mitchell	3357	2/07/2015
Vic Monarca	2053	6/07/2016
Wessel Mulder	7351	31/12/2017
Peter Nicholson	4086	31/12/2020
Stephen Nixon	2256	31/12/2017
Eric Norman	7430	31/12/2016
Dennis O'Loughlin	7353	31/12/2017
Gerald Owen	7341	31/12/2016
Clifford Parkes	3607	31/12/2020
Mervyn Perry	268	31/12/2017
Lorraine Pidgeon	1513	31/12/2017
Graham Porten	2257	31/12/2019
David Power	2487	19/04/2015
Daniel Price	4129	30/06/2016
John Puljak	3780	12/08/2015
Barry Punter	1843	31/10/2015
Greg Reece	3508	19/04/2015
Tony Ridgers	421	31/12/2020

Rick Roberts	1316	28/02/2016
Dean Rowe	4200	2/07/2015
Ian Savage	259	14/04/2016
Valentine Scriha	1896	12/08/2015
Kevin Sellars	7352	31/12/2017
Kevin Sharman	627	30/11/2015
Tracey Sherman	1829	31/12/2018
Douglas Shipley	2221	2/07/2015
Michael Sillis	844	31/12/2017
Gary Smith	2512	31/12/2019
Trevor Smith	1035	31/12/2017
Laurence Snook	1526	31/12/2017
Dragan Stevanovic	2960	31/12/2018
Neil Stewart	1358	31/12/2017
Steven Stock	3923	6/07/2016
Steve Storey	3176	29/02/2016
Raymond Street	3173	31/05/2016
Peter Sutton	3183	31/12/2017
Russell Tierney	2000	31/12/2020
Dennis Tremain	1036	31/12/2017
Andy Vesco	3783	19/04/2015
Paul Vince	7355	31/12/2017
Charles Vincent	1827	31/03/2016
Mark Weston	883	31/12/2017
Charles Wheeler	3943	31/12/2020
Shane White	2869	31/08/2016
Craig Williams	4176	31/12/2020

Originally published in the
Construction Specifier May 2015
www.constructionspecifier.com

Duplex Stainless Steel Revolutionises Structural Design

Catherine Houska, CSI

Architectural and engineering firms are increasingly exploring stainless steel's possibilities as a structural material as new research, structural codes, and design guides become available. Most designs have used the familiar Types 304L or 316L alloys from the austenitic family of stainless steels, but for all but the lightest sections, the duplex stainless steel family presents a much greater potential for innovation. Many architects and engineers are unaware of this interesting stainless steel alloy family.

The alloys in the duplex stainless steel family combine a wide range of corrosion resistance (similar to austenitics) with significantly higher strength levels than both common carbon steels and austenitics. This can allow designers to reduce structural section sizes, which can dramatically change design, or use a more corrosion-resistant stainless steel without a significant raw material cost differential. Cutting edge lightweight pedestrian bridges have been the most common duplex stainless steel application to date, but they are also being used for glass curtain wall supports, sunscreens, railings, concrete reinforcement, sculpture, and other structural applications.[1]

What is duplex?

It is common for architects and designers to simply specify "stainless steel," not realising there are five distinct alloy families—austenitic, ferritic, duplex, martensitic, and precipitation hardening—and hundreds of individual alloys. The most commonly used stainless steels for building and construction are the austenitics (e.g. 304/304L, 316/316L), which combine corrosion resistance with formability. They are used for a wide range of aesthetic, practical and structural applications. Small sections can be cold-worked to increase strength levels.[2]

Stainless steel family names are derived from their characteristic microstructures. For example, austenite gives austenitic stainless steels their name and makes them non-magnetic, very formable, and weldable. The ferrite in the microstructure of mild steel, cast iron, and ferritic stainless steels (e.g. 430, 444) makes them magnetic. Ferritic stainless steels are less formable and weldable then austenitics.

First introduced in 1930, duplex stainless steels have mainly been used for corrosive industrial applications. Their name refers to their combined austenite and ferrite microstructure. The formability and weldability of these alloys are between those of the austenitic and ferritic stainless steels. Designers familiar with precipitation hardened (PH) stainless steel bolts (e.g. 17-4 PH) know duplexes are not the strongest stainless steels, but the PH alloys are less corrosion-resistant then Type 304 and not suitable for more severe environments unless they are protected. Duplexes are the only alloy family to provide both exceptional corrosion resistance and high strength.

Figure 1 provides the relevant ASTM and American Welding Society (AWS) standards and specifications for duplex stainless steel; Figure 2 (page 51) compares the mechanical properties of the stainless and carbon steels used for structural shapes. Figure 3 (page 52) compares the impact toughness of austenitic, duplex, and carbon steel at different temperatures—important for safety and security applications.

Standard	Specification nunber	Description
ASTM		
Plate, sheet, strip	A240/A240M	Chemical composition and mechanical properties
	A480/A480M	Finishes, dimensional tolerance, flatness, and shipping requirements
Hollow sections*	ASTM A554	Round, square, and rectangular stainless steel mechanical and structural tubing chemical composition, mechanical property, and dimensional tolerance requirements
Bars and shapes	A1069/ A1069M	Laser-fused (laser-welded) stainless steel structural shapes
	A276**	Hot and cold rolled or extruded rounds, squares, hexagons, angles, tees, channels, and other structural shapes chemistry and mechanical properties
	A484/A484M	Dimensional tolerance, straightness, and finish descriptions for the products in A276
Bolts	A1082/ A1082M	High-strength duplex stainless steel bolts
Concrete reinforcement	A955	Round and deformed concrete reinforcement
	A1022	Deformed and plain stainless steel wire and welded wire mesh
American Welding Society (AWS)		
Structural*	D1.6	Structural welding code for stainless steel

* Duplex stainless steel hollow sections are also covered byA789 (tube), along with A790 and A928 (pipe), but those standards are for American Society of Mechanical Engineers (ASME) pressure vessel code products that carry liquids under pressure and require additional pressure testing that is not needed for a structural application. A554 includes large diameters and heavier walls; it is a more cost effective choice then 'pipe' for structural applications like bollards.

** Carbon steel welding codes should never be used for stainless steel, as there are important differences. A1069 only covers laser-welded structural shapes; all other welded structural shapes should be specified using AWS D1.6 in combination with ASTM A240 and A480.

Figure 1. Specifications for duplex stainless steel structural products.

Design codes and guides
Stainless steel has been used selectively since the 1940s for bridges and other structural applications.[3] Formal stainless steel structural design guidance first became available in 1968 when research prompted by the design of the Gateway Arch in St. Louis was published as an American Iron and Steel Institute (AISI) specification. The current version of this standard, Structural Engineering Institute/American Society of Civil Engineering (SEI/ASCE) 8, Specification for the Design of Stainless Steel Cold-formed Structural Members, covers light-gauge austenitic and ferritic stainless steels. It was the basis for cold-formed stainless steel structural design standards in Europe, Australia, New Zealand, South Africa, and Japan.

The first large structural stainless steel non-industrial projects to use this research were the 1964 Unisphere sculpture (World's Fair, New York City) and the following year's Gateway Arch, which were both Type 304. The 1986 restoration of the Statue of Liberty used Type 316L and UNS 32550 duplex stainless steel to replace much of the original iron support framing and is the first known large non-industrial duplex structural application. The more recent 7 World Trade Center used both Type 316L and 2205 duplex for structural applications. By far, the largest construction-related structural application for duplexes (not including industrial buildings) has been bridges.

There has been substantial international structural design research done on stainless steel since the 1960s, including design for seismic, fire, and blast wall applications. In 1993, work began to add heavier stainless steel sections to the European standards. EuroCode 3, *Design of Steel Structures, Supplementary Rules for Stainless Steels, Part 1–4*, includes both light and heavy austenitic and duplex stainless steel structural sections. China just added stainless steel to their structural design codes as well. Stainless steel-framed European and Japanese buildings were built to justify code additions. In 1995, EuroCode 3 was used in the design of the Canadian National Archives (Types 304L and 316L structural framing) to avoid coating VOCs.[4]

Until recently, there was no North American guidance on the design of heavier structural sections. American National Standards Institute/American Institute of Steel Construction (ANSI/AISC) 360, *Specification for Structural Steel Buildings*, only covers heavier carbon steel structural sections. In September 2013, AISC Steel Design Guide 27, *Structural Stainless Steel*, was issued to provide design advice for sections 3.2 mm (0.125 in.) or greater. Capitalising on new research that will be incorporated into EuroCode 3, it includes welded plate fabrications, extruded and rolled shapes, hollow sections, tensile bars, and fasteners.[5]

The AISC design guide includes three duplex stainless steels (e.g. UNS S32101, S32304 [2304], S32205 [2205]) and can be applied to other stainless steels within this family—such as UNS 32003, which was used for subway canopies in Washington, D.C. Figure 2 (page 51) compares the mechanical properties of the structural stainless and carbon steels used for heavier sections.

Alloy selection
Stainless steel alloy specification for corrosion resistance has been discussed in greater detail in previous articles.[6] While there are common names (e.g. 304, 316) for many stainless steels, alloy chemistry should be specified using the international Unified Numbering System (UNS) and internationally recognised specification (e.g. ASTM, EN, JIS) to avoid miscommunication.

Figure 4 (page 53) provides the chemistries and Pitting Resistance Equivalent Numbers (PREn) for the austenitic and duplex stainless steels in the AISC design guide and UNS 32003. PREn is a calculation based on the alloying elements that determine the corrosion resistance of stainless steel (e.g. chromium, molybdenum, and nitrogen) to pitting corrosion. Surface finishes, welding, environmental exposures, and other factors can be as important, so PREn should not be used exclusively for specification.

	UNS	Common name	Tensile strength	Min. Yield strength	Minimum elongation in 50 mm (2 in.)
A240A240M-15 Stainless steel					
Austenitic	S30400	304	515 MPa (75 ksi)	205 MPa (30 ksi)	40%
	S30403	304L	485 MPa (70 ksi)	170 MPa (25 ksi)	40%
	S31600	316	515 MPa (75 ksi)	205 MPa (30 ksi)	40%
	S31603	316L	485 MPa (70 ksi)	170 MPa (25 ksi)	40%
	S31703	317L	515 MPa (75 ksi)	205 MPa (30 ksi)	40%
Duplex	S32101		650 MPa (94 ksi)*	450 MPa (65 ksi)*	30%
	S32304	2304	600 MPa (87 ksi)	400 MPa (58 ksi)	25%
	S32003		655 MPa (95 ksi)**	450 MPa (65 ksi)*	25%
	S32205	2205	655 MPa (95 ksi)	450 MPa (65 ksi)	25%
A1043/A1043M-14 Carbon steel					
Grade 36			400 MPa (58 ksi)	250 MPa (36 ksi)	23%
Grade 50			450 MPa (65 ksi)	345 MPa (50 ksi)	21%

* These values apply to material of thickness less than 5 mm (0.187 in.). For thicker material, the minimum tensile strength is 700 MPa (101 ksi) and yield strength is 530 MPa (77 ksi).
** These values apply to material of thickness less than 5 mm (0.187 in.). For thicker material, the minimum tensile strength is 690 MPa (100 ksi) and yield strength is 485 MPa (70 ksi).

Figure 2. Minimum mechanical properties of the stainless and carbon steels used for structural sections.

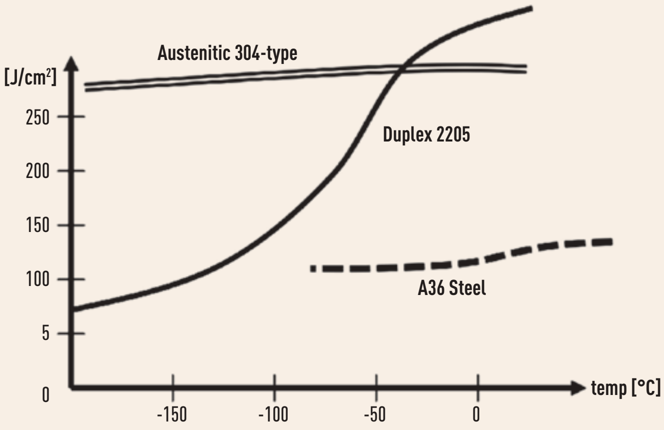


Figure 3. The relationship between impact toughness and temperature for austenitic and duplex versus carbon steel.
Image courtesy Steel Construction Institute.

The 1986 restoration of the Statue of Liberty used duplex stainless steel to replace much of the original iron ore support framing.
Photos © Mike Renlund and Erik Cleves Kristensen (inset).

Based on the assumption corrosion staining is undesirable and there will be little or no maintenance cleaning, UNS S32101, S32304, and proprietary stainless steels with similar corrosion resistance to Type 316/316L are generally suitable for low to moderate salt exposure or polluted environments where there is regular heavy rain to clean surfaces.

UNS S32205 provides substantially more corrosion resistance and is suitable for higher levels of industrial pollution and salt exposure, when rougher finishes are specified, or where natural heavy rain cleaning is less frequent. Even more corrosion-resistant stainless steels are available for saltwater immersion and other particularly aggressive environments.

This article examines various new construction and restoration projects in both the United States and from around the world to help illustrate the reasons why certain stainless steels are specified.

Statue of Liberty restoration
Since its installation in New York in 1886, the Statue of Liberty has become one of the most well-known sculptures in the world. However, many people are not aware galvanic corrosion caused structural deterioration, making a significant restoration necessary in 1986.[7]

The original structure of the 46-m (151-ft) statue had a framework of puddled iron consisting of three distinct components—a central pylon, 1850 secondary framing beams, and armature bars. A double-helix staircase rises through the pylon's center. About 1500 U-shaped copper saddles connected the armature to the outer copper envelope sheets.

Designers Auguste Bartholdi and Gustave Eiffel anticipated the galvanic corrosion problem and tried to electrically isolate the materials. Unfortunately, the envelope design and subsequent modifications allowed rain containing coastal salt and acid from pollution to seep behind the copper. Condensation from temperature and humidity changes also adds the moisture necessary for corrosion.

Located in Qatar, the Jahn-designed Doha Covention Center uses cable-net-supported glass walls to create a floating roof plane. Due to its structural properties and corrosion resistance, duplex stainless steel was specified for the façade.
Photo courtesy Jahn.

	UNS	Carbon	Manganese	Chromium	Nickel	Molybdenum	Nitrogen	Copper	PREn
Austenitic	S30400	0.03		17.5–19.5	8.0–10.5				18–19
	S30403	0.03		17.5–19.5	8.0–12.0				18–19
	S31600	0.03		16.0–18.0	10.0–14.0	2.00–3.00			24–25
	S31603	0.03		16.0–18.0	10.0–14.0	2.00–3.00			24–25
	S31703	0.03		18.0–20.0	11.0–16.0	3.00–4.00			30–33
Duplex	S32101	0.03	4.00–6.00	21.0–22.0	1.35–1.70	0.10–0.80	0.20–0.25	0.10–0.80	25–27
	S32304	0.03		21.5–24.5	3.0–5.5	0.05–0.60	0.05–0.20	0.05–0.60	25–28
	S32003	0.03		19.5–22.5	3.0–4.0	1.50–2.00	0.14–0.20		30–31
	S32205	0.03		22.0–23.0	4.5–6.5	3.0–3.5	0.14–0.20		35–36
Note: Remainder iron, PREn = Cr + 3.3(Mo +0.5W) + 16N									

Figure 4. Primary chemical composition and pitting resistance equivalent number (PREn).

Date	Name	Location	Type of bridge	Duplex stainless steel
1999	Suransuns Bridge	Switzerland	Stress ribbon, 40 m (131 ft)	S32205
2001	Millennium Bridge	London, England	Tilted box girder arch, 80 m (262.5 ft)	S32205
2002	Apate Bridge	Stockholm, Sweden	Tied beam pedestrian bridge	S32205
2004	Likholefossen Bridge	Norway	Lightweight pedestrian, 24-m (79-ft) span	S32101
2006	Siena Bridge	Ruffolo, Italy	Cable stayed pedestrian, 60 m (197 ft)	S32101
2006	Celtic Gateway Bridge	Holyhead, Wales	Load bearing arch, 160 m (525 ft)	S32304
2008	Zumaia Bridge	Spain	Composite FRP duplex	S32205
2009	The Helix	Marina Bay, Singapore	Tubular, 280 m (918.6 ft)	S32205
2009	Meads Reach	Bristol, England	Stressed skin arch	S32205
2009	Sant Fruitos Bridge	Spain	Arch	S32101
2011	Harbor Drive Bridge	San Diego, United States	Cable stay, 162 m (531.5 ft)	S32205

Figure 5. Some completed pedestrian duplex stainless steel footbridges, as found in Sustainable Duplex Stainless Steel Bridges, *a U.K. Steel Construction Institute publication by Nancy Baddoo and A. Kosma.*

Severe corrosion of the iron armature had occurred by 1981 and caused copper damage. Type 316L stainless steel replaced the iron armature except for a few bars in the right sole of the foot. No galvanic corrosion problem would be expected between copper and stainless steel in this type of environment and their coefficients of thermal expansion are the same. A high-strength, highly corrosion-resistant duplex stainless steel UNS S32550 secondary framework was used to support the new Type 316L armature.

Buildings

Duplex stainless steel's inherent corrosion resistance and opportunities for unique structural designs have made it a desirable material for both form and function in many buildings around the world.

Boston-area research building

The strength and corrosion resistance of duplex 2205 and Type 316L stainless steels are being used to support a unique façade in Boston. The building reflects its environment by using the light-gray New England granite found in many of the city's historic buildings. Unlike traditional heavier buildings, the airy modern design uses the stone as a secondary façade in front of a glass curtain wall. The stone will appear to come out of the landscape and gently float up the glass exterior.

The stone will sit on a Type 316 framing and shelving system, which is held off the building by large 2205 struts and cleat plates. This design takes advantage of the corrosion resistance of both stainless steels and uses the much higher strength duplex 2205 to carry the primary structural load.

The higher corrosion resistance of the 2205 is important because it will be visible to building occupants. Its location behind the stone means it will be exposed to coastal and de-icing salt, but not readily rain-washed—this means resistance to corrosion is critical. Completion is expected in 2016.

Doha Convention Center

Located in Qatar and adjoining the harbor, the Doha Convention Center is still under construction. International architectural firm Jahn's design uses cable-net-supported glass walls to create a floating roof plane. Its strong horizontal expression complements the verticality of the surrounding towers.

Due to its structural properties and corrosion resistance, duplex 2205 was used for the façade cross-bars. Most of the other façade components are Type 316/316L. Type 317L, which is more corrosion-resistant then Type 316, was employed for many of the stainless steel landscape components (e.g. dot lights, semi-recessed planters) and exterior handrails. The interior decorative metal cladding is Type 316.

The high strength of duplex stainless steels makes them ideal for tension bars when designers want to minimise structural section size and maximise the view through large glass curtain walls. The first large glass curtain wall application to use the strength of 2205 duplex to minimise the size of the structural support sections was SOM's New Poly Plaza, completed in Beijing in 2007.[8]

Fondation Louis Vuitton Museum

Frank Gehry's design for this new Parisian museum is reminiscent of billowing transparent sails and was influenced by the iconic 19th century Parisian glass pavilions. The building consists of three primary components—the museum's inner core display areas (iceberg) with its concrete exterior, a secondary exterior structure of steel beams and wooden tripods, and a tertiary structure of billowing glass sails supported by a duplex grid.[9]

The glass sails on the secondary structure consist of painted steel columns, wooden beam 'tripods,' and a large 2205 duplex stainless steel grid that support glass sails weighing between 200 and 350 tonnes (220 and 386 tons). Three large sails serve as an umbrella for the building while nine others sweep around it creating the appearance of a 'ghost ship,' sailing above the treetops of Bois de Boulogne. To recover rainwater, 2205 gutters are used.

Duplex 2205 stainless steel plates were also inserted into the wooden beams at their connection points with the steel beams to strength the connections. Each of these connection points also used a complex 100-mm (3.9-in.) thick carbon steel/2205 duplex hybrid plate node to connect the wood and metal elements. These nodes ensure structural stability while permitting movement. About 1500 tonnes (1654 tons) of 2205 were used for this project.

Middle East cultural center

Construction will be completed this year on a cultural center near where Saudi Arabia's first oil was discovered. The geology and rock formations influenced the design's four visible rounded above-ground components—the library, keystone, tower, and auditorium.

A tower soars above the rest of the complex and is surrounded by smaller 'mountainous' forms. These shapes are clad in high-strength duplex 2205 stainless steel sunscreen façade composed of 250 km (155 mi) of 76.1-mm (3-in.) tubing. Duplex 2205 was selected because of corrosion research conducted on various stainless steels and architectural metals at a Dubai test site by stainless steel and high-performance alloy producer Outokumpu, with the assumption there will be no manual cleaning.[10]

The project's engineering design firm had to consider the corrosiveness of the coastal environment, wind loading from sand storms, durability requirements, and the unique curving shape of the sunscreen façade. The curves of tubular screen resemble the loops of a fingerprint and also snuggly wrap around the exterior curves of each building shape. Where the sunscreen façade extends across solid walls, it is 88 percent closed—this prevents the sun from reaching the surface and heating it. As it reaches windows, the sunscreen transitions gradually to a flattened tube 12 mm (0.47 in.) in height, creating an 84 percent open area. The angle of the flattened tubes prevents sun from reaching the windows and transferring heat into the building while giving visitors a minimally obstructed view.

The world's first duplex stainless steel sunscreen was the Stockholm Congress Centre, which used Z-shaped 2205 stainless steel beams with a semi-reflective matte finish because of its corrosive harbor-side location.[11]

Frank Gehry's design for Paris' Fondation Louis Vuitton Museum takes its cues from billowing transparent sails and 19th century glass pavilions.
Photo © Todd Eberle (left) and Iwan Baan (right).

Pedestrian bridges
High-profile pedestrian bridges can change the urban landscape, creating new city gateways or connections highlighting and increasing the use of new or redeveloped areas. Rather than being purely utilitarian, stainless steel pedestrian bridges are often sculptural—inviting active public interaction. They are an evolving means of expression giving the architects and engineers the opportunity to develop and test cutting-edge concepts. The inherent corrosion resistance of stainless steel and ability to eliminate coatings makes design elements and connections into artistic details.

The first stainless steel bridge to garner international attention and become a significant tourist attraction was London, England's Millennium Bridge (2001) designed by Foster and Partners, Anthony Caro, and Ove Arup and Partners using duplex 2205. Figure 5 (page 53) provides a listing of some of the completed duplex stainless steel bridges and their locations.

In addition to providing the corrosion resistance necessary to offer the longevity expected of iconic bridges, their high strength and other design characteristics can make it possible to reduce structural component size, making these beautiful bridges more cost competitive. Currently, the longest duplex stainless steel pedestrian bridges in the world are The Helix in Marina Bay, Singapore (280 m [920 ft]) and the Harbor Drive Pedestrian Bridge in San Diego, California (168 m [550 ft]). Both used UNS S32205 duplex stainless steel as a primary structural material in their innovative, cutting-edge designs.

The Helix
Completed in 2010, the Helix Bridge, previously known as the Double Helix or DNA Bridge, is a new landmark linking Singapore's Marina Centre with Marina South.[12] The world's first double-helix bridge is part of a high-profile development project and completes a 3.5-km (2.2-mi) pedestrian walkway around Marina Bay. The design consortium included architects COX Group Pte. (Australia), Architects 61 (Singapore), and the engineering firm Arup.

Two delicate helix duplex 2205 stainless steel structures surround the walkway and act as a tubular truss to resist design loads. That same material was also used for the cantilevered viewing 'pods' that extend out from the bridge and the slender concrete-filled support columns. The high strength of the duplex stainless steel pipes made much lighter sections possible for a total bridge weight of 1700 tonnes (1873 tons). It is estimated a conventional box girder bridge would have used five times as much carbon or weathering steel. When maintenance painting and other costs were considered, the 100-year design life analysis showed 2205 was a lower cost option than carbon steel.

Harbor Drive Bridge
Opening in 2011, San Diego's Harbor Drive Pedestrian Bridge is one of the longest self-anchored pedestrian bridges in the world. Designed to last at least a century, the elegantly simple lines of this horizontally curved structure mimic the look of the sailboats on the adjoining harbor.

Completed in 2010, the Helix Bridge is a new landmark for Singapore.
Photo © Kinsman.

The Helix Bridge in Singapore.
Photo © Kinsman.

The streamlined design is different from traditional suspension bridges, using a design that hides the main tension cables inside welded pipes. The main cable is enclosed within a 203 mm (8-in.) stainless steel pipe, and extends from the ground to the top of a single 40-m (131-ft) inclined pylon along the inside of the curve. Thirty-four suspender cables connect the inside edge of the curved deck to the main cable pipe. A second longitudinal post-tensioned cable is hidden inside the 203-mm stainless pipe above the inside railing and provides horizontal force to stabilise the bridge.

Designers chose high-strength corrosion-resistant duplex 2205 stainless steel because of the alloy's strength and the site's regular salt fog exposure and longevity requirements. The designers fully utilised the high strength of this alloy. Type 316 austenitic steel was used for the suspender cables and safety mesh. The connectors for the cable system are 2205.[13]

New Middle East bridge

A spectacular new pedestrian bridge project is nearing completion in the Middle East. Taking full advantage of the unique characteristics of the specified materials, it consists of two cable-stayed bridges that repeatedly curve apart and then intersect, creating a graceful series of figure eights. The design concept was a necklace being draped along the ring of the island marina. The open areas between the curving bridges are glass-floored for evening activities. Each bridge is approximately 200 m (656 ft) long and spans 90 m (295 ft) over the water from one quay to the other.

As the Middle East coast is a corrosive environment, duplex 2205 stainless steel was used for all the visible steel structural elements, including the supports for the cantilevered glass floors and concrete decks, along with canopy structures and bridge balustrade posts. The bridge pylons are also clad in duplex 2205 plate, which is structural, offers corrosion protection, and applies compression to the pylons.

Conclusion

The high strength and corrosion resistance of duplex stainless steels make them suitable choices for building and construction structural applications including bridges, railings, glass support structures, and sunscreens where strength and corrosion resistance is important. The revised EuroCode and new AISC and Chinese design guidance has made it much easier for firms to design with structural stainless steel.

Alloy specification guidance is available from articles, industry associations, and producers. In more corrosive locations, however, the assistance of an expert in stainless steel atmospheric corrosion should be obtained to verify appropriate alloy specification.

Notes

[1] This author acknowledges the International Molybdenum Association (IMOA), the Nickel Institute, Outokumpu, Pedelta, T.Y. Lin, Arup, TriPyramid, Buro Happold, MTec, and Nancy Baddoo of the U.K. Steel Construction Institute for assistance in the preparation of this article.

Opening in 2011, San Diego's Harbor Drive Pedestrian Bridge is one of the longest self-anchored pedestrian bridges in the world.
Photo © Fred Kaplan.

[2] See this author's previous articles in *The Construction Specifier*: "Metals for Corrosion Resistance: Part II" (November 2000), "Architectural Metal Corrosion: The De-icing Salt Threat" (December 2006), "Designing on the Waterfront" (November 2007), and "Stainless Steel for Severe Corrosive Environments" (September 2011)—the last two are available at www.constructionspecifier.com. Also see this author's "Stainless Steel in Architecture, Building and Construction: Guidelines for Corrosion Prevention" (i.e. Reference book series No. 11 024-2001 for the Nickel Institute) and the IMOA publications, "Which Stainless Steel Should I Specify for Exterior Applications?" and the third edition of "Duplex Stainless Steel Fabrications."

[3] For more on this topic, see this author's previous article in the April 2007 issue of *The Construction Specifier*. "Pushing the Design Envelope with Structural Stainless Steel" can be found in the Archives at www.constructionspecifier.com.

[4] Ibid.

[5] AISC offers a pre-recorded three-hour webinar on this design guide, given by this author and Nancy Baddoo. Visit www.aisc.org/content.aspx?id=38396.

[6] See note 2.

[7] For more, see "The Statue of Liberty Restoration," in *Proceedings of The Statue of Liberty: Today for Tomorrow Conference*, published by National Association of Corrosion Engineers (NACE), from the 1986 event it co-sponsored with the National Parks Service.

[8] The U.K. Steel Construction Institute published its Structural Stainless Steel Case Study 09, *New Beijing Poly Plaza Cable-Net Wall*, in 2011.

[9] See "Duplex Rigging for Glass Sails," in the January 2015 issue of IMOA's *MolyReview*.

[10] See this author's September 2011 article, mentioned in note 2.

[11] See this author's article, "Designing Sunshades into the Façade: Stainless Steel Selections" in the June 2012 issue of *The Construction Specifier*.

[12] See the U.K. Steel Construction Institute's Case Study 11, *Helix Pedestrian Bridge*.

[13] "The Harbor Drive Pedestrian Bridge," an article by Joe Tognoli and Dan Fitzwilliam (T.Y. Lin), appeared in the Spring 2011 issue of *Aspire*.

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Protecting Public Art Against Corrosion

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Public art comprises art objects and artwork that are sited outside and exposed to the environment in the public domain. Outdoor sculptures form an integral cultural part of any community. Sculptures and statues are sometimes erected in commemoration of a particular event or for an important figure in time past (*Figure 1*). They also serve as an important landmark for the community in which they stand (*Figure 2*). In other cases an outdoor artwork is erected as a way of enhancing the surroundings in which artwork is located, such as in sculpture parks.

Figure 1. Heavily patinated 17th Century bronze statue in a European city.

Figure 2. Modern sculpture - giant equine heads (kelpies) clad in stainless steel; Scotland.

Although the patina formed on an outdoor sculpture is often an aesthetic effect desired by the artist and the owner, the most common problem from an engineering and aesthetic perspective encountered on metal sculptures is *unintended* corrosion. Conservation and restoration of outdoor sculptures is an important activity dedicated to the preservation, protection and maintenance of art objects. The conservation and maintenance of an outdoor sculpture may be tailored to the needs of a particular piece of artwork at a specific location. Preservation methods employed on an outdoor sculpture must take into account factors such as the artist's intentions, the existing condition of the artwork, and the immediate environment in which the object is located.

Repair and maintenance works on outdoor sculptures often include surface cleaning, physical repairs and removal of corrosion products, followed by application of an anti-corrosive surface treatment or sacrificial protective coating. The maintenance and restoration of outdoor sculpture in the public domain is often undertaken or overseen by a professional conservator rather than being included in a generic program of asset maintenance. A standard remediation procedure that gives good results on a sculpture in one location may not be appropriate for a similar art object at another location.

Restoration and conservation methods used in the past on outdoor artwork

In time past one of the main ways to remove corrosion from metal art objects was by chemical means. Sculptures may have been spot treated, or the sculpture may have been completely submerged in a chemical bath. The chemical treatments usually resulted in the removal of any patina and surface deposits, thereby returning the bronze to its original condition. However, the chemical method often produced severe results, such as attacking the metal surface and leaving the object with an unpleasant appearance. The chemical treatment method for metal sculptures is still employed to this day with controlled variations that are not as aggressive as used in the past.

Another approach to the conservation of metal sculptures in the past (often bronze) was to simply not treat the art object at all. As expected, this approach had widely varying results. Some metal-base sculptures survived in acceptable condition while others became degraded and fragile over time. Many outdoor sculptures are prized for their original patinas, such as ancient Chinese bronzes, thus in some instances conservators may purposefully not carry out treatments on specific public artwork.

Another method employed in the past, that is not very different from treatments that are still in use today, was to dry the art work, carefully remove any visible corrosion manually or mechanically, and seal or coat the surface of the metal object with wax of lacquer. Other corrosion removal methods employed in the past included application of a variety of substances on the object surface, ranging from secret concoctions to materials as mundane as a proprietary oven cleaner or lemon juice.

The restoration methods used on outdoor sculptures in past centuries had strengths and weaknesses. However, the well-founded intention of sculptors, restorers and conservators in the past was to ensure that art objects survived the ravages of time and exposure in the outdoor environment in order to be available for the enjoyment of future generations.

Contemporary methods for restoration and conservation of outdoor artwork

Assessment of the artwork condition. Nowadays, conservation of outdoor art objects has a robust scientific basis. Before any conservative action can be taken on an outdoor sculpture a condition assessment of the art object is carried out. The assessment process includes, but is not limited to, reviewing past conservation condition and conservation reports, preparing a current photographic survey, assessing the structural integrity, undertaking scientific analysis, and, if possible, holding discussions with the artist, fabricator and asset owner as to the implementation and desired outcomes of any conservation treatment. It may also be the case that a trial of an appropriate conservation treatment will be carried out prior to any restoration being undertaken on the art object.

There are generally five steps that come with the condition assessment of an outdoor metal sculpture. The five steps involved are as follows:

1) Technical description of the art object. The description includes identification of the materials, information on the construction methodology, assessment of past maintenance practices, determination of the present surface condition, characterisation of the deterioration and corrosion products, and description of the structural integrity. Also of value are descriptions of the effects of maintenance treatments and repairs undertaken in the past.

2) Determination of the causes of degradation or corrosion. This involves an evaluation of the effects of the surrounding environment of the artwork where it is staged.

3) Maintenance recommendations for the sculpture. The recommendations are based on the history, condition, location of the sculpture, the cause of deterioration, resources of the owner, and the relative needs of the sculpture in the context of an entire public art asset collection.

4) Assignment of treatment priorities. The conservator can assign priorities based on technical information that has been gathered. The priorities are assessed in relation to the risks to the art object in the short, medium, and long term, the risks to public health and safety, the funds available, and other relevant site specific issues.

5) Estimate of the resources required. The labour costs of the proposed maintenance options are expressed in monetary terms or in hours of work required for conservators, technicians, and other specialists, for example, a corrosion consultant. Supplies required and the equipment costs for the restoration are included at this stage.

The conservation project for the outdoor sculpture then moves to the next stage where the methodology for conservation or restoration and repair of the art object is determined, planned, and carried out.

Cleaning and removal of corrosion products and surface deposits

The removal of encrustations, adherent deposits and corrosion products off the surfaces is an important first step in the remediation of an art object after the initial condition assessment is completed. There are many techniques that are available to carry this process out and a number of the standard conservation procedures are outlined below:

Hand cleaning. The basic method for removing corrosion products and deposits off an outdoor sculpture is by manual cleaning. The cleaning method can include heating to soften old wax and applying a solvent at a specific location to dissolve and remove the wax or old coatings. This is followed by removal of surface debris with a plastic spatula and dental tools.

Water blasting. Another mechanical method for cleaning an outdoor sculpture is by pressure water blasting. The water can be pressurised to varying levels depending upon the pressure needed for an individual case. Different nozzle types on a water blaster can direct the flow of water in various ways, which provides versatile cleaning of the surface of the art object.

Abrasion by surface peening. Peening is used in the conservation profession for the cleaning of metal objects that need to be precisely prepared. Peening with glass beads leaves no residue and produces a relatively clean surface. Unwanted scales, accretions or corrosion products are knocked off the metal surface by the force of the blasting.

A metal sculpture surface can also be peened on a microscopic scale. However, some conservators oppose the use of glass bead peening for reasons such as it can remove metal from the surface thereby decreasing the corrosion resistance of the artwork. Alternative peening methods that are less abrasive than glass bead peening include abrasion with crushed walnut shells and the use of dry ice blasting (1).

Preservation tools and materials used in conservation of outdoor artwork

The application of a coating material onto the surface of an outdoor sculpture is a common conservation method. Coatings are selected for their durability, adhesion, ease of maintenance and surface appearance. Considerable research has gone into identifying and testing the best coating materials for protecting outdoor sculptures (2). The selection of an appropriate coating system for a sculpture is governed by factors such as the existing metal surface, environmental considerations, and the degree of maintenance that is expected.

Gloves and cloths. For outdoor sculptures nitrile or similar gloves are utilised. Soft cotton cloths are commonly used to buff wax coatings on metal sculptures once they have cooled and hardened.

Detergents. Neutral or non-ionic detergent solutions are used for the preliminary washing of an object to help remove surface deposits. Detergents increase the wetting action of water thereby increasing its ability to remove grime and other undesirable matter adhering to the surfaces of an outdoor sculpture.

Waxes. There are many types of natural and proprietary waxes that have been evaluated and used in conservation work for protecting outdoor art objects (3,4,5). Carnauba wax or beeswax suspended in a solvent (e.g. turpentine) perform well on metal patinas and they are fast drying. However, if waxes are applied onto a warm metal surface they may smear or cause deposits to build up.

Brushes. Soft bristle brushes are often used for the application of liquefied wax onto the surface of a sculpture. Paint brushes may be employed for the initial cleaning of a metal object with tape wrapped around the metal ferrule of the brush so that the ferrule does not make direct contact with the sculpture surface causing scratching.

Lacquers and corrosion inhibitors. Proprietary lacquers have been evaluated and employed as protective coatings for metal sculptures over many years (6). A proprietary product called *Incralac* is a clear acrylic lacquer that has often been used for outdoor copper alloy sculpture conservation (7). *Incralac* is made of a synthetic resin with the addition of a corrosion inhibitor (benzotriazole, BTA). *Incralac* is a durable lacquer for outdoor exposure conditions and it also has a UV stabilising property which is beneficial for the longevity of the lacquer on metal art objects.

Whatever method of conservation or restoration is chosen for an outdoor sculpture, the methodology, remediation procedure and outcome of restoration, must be properly documented. The record should include collation of the condition assessment, results of testing or trials, and a detailed description of the remedial work that was carried out. The latter should include photo documentation and a list of the materials and equipment utilised. Comprehensive documentation of a treatment is the best means to ensure that future conservation work can be carried out with all available knowledge of the past history of the artwork.

Case Studies of Corrosion Issues on Outdoor Sculptures

In the following section a number of case studies of corrosion issues relating to outdoor sculptures made of different materials are outlined. The selected cases illustrate short term and long term problems encountered when outdoor sculptures have been affected by atmospheric corrosion. Each case illustrates degradation of the sculpture material due its location in a specific environment. In three of the cases the artwork was able to be reinstated by carrying out an appropriate restoration procedure. In the fourth case it was considered important by the artist and sculpture owners to carry out preliminary research to identify the most appropriate remediation treatment available before restoration of a prominent public artwork proceeded.

Restoration of a 100 year old bronze statue

A bronze statue of Queen Victoria (Francis Williamson sculptor) was commissioned for her Diamond Jubilee. The bronze statue was installed in Albert Park, central Auckland city in 1889. The Queen Victoria sculpture, mounted on a large granite pedestal, was unveiled before a large public gathering at Albert Park in that year. After more than 100 years of exposure in the marine environment that prevails in Auckland city, the bronze statue exhibited extensive and disfiguring corrosion. In response, in 2006 Auckland City commissioned a conservation and restoration project to be undertaken on the well-known bronze statue.

A description follows of the Queen Victoria bronze statue condition, after an assessment had been carried out by conservators (8). The sculpture showed severe corrosion of the bronze partially due to intricate detail and raised texture of the cast bronze surface. The bronze surface was covered with streaks, run-offs and disfiguring corrosion layers. Corrosion testing on the bronze confirmed the presence of localised chloride corrosion products, particularly *atacamite* [$Cu_2(OH)_3Cl$]. The corrosion on the cast bronze was not uniform; there were heterogeneities present on the metal surfaces such as pores and boundaries between areas enriched with metallic inclusions (tin and zinc).

The imperfections on the bronze surfaces had become preferential sites for corrosion processes, e.g. pitting corrosion. From the exterior, it appeared that pitting and perforations had developed on the bronze particularly around the neck of the figure. Some years prior, the head of the figure had to be re-welded to the body along the neckline following an act of vandalism that decapitated the statue. If fragments of the iron casting armature or ferrous metal pins or bolts were still present in the interior of the cast bronze, there was the possibility of galvanic corrosion occurring. The granite pedestal and plinth on which the statue was displayed were in good condition, with some losses of the gold leaf inscription.

The conservators decided that the specification for the treatment and remediation of the bronze Queen Victoria statue (*an intervention*) should be as follows:

Figure 3. Bronze statue of Queen Victoria being removed by crane at Albert Park

Figure 4. Queen Victoria statue showing extensive corrosion on the bronze surfaces.

Figure 5. Bronze statue after treatment to remove corrosion. Repairs were made at the neck area.

Figure 6. The bronze statue of Queen Victoria treated, patinated and waxed before re-installation.

1) Remedial conservation treatment. Once the statue had been removed to an indoor location (*Figures 3 and 4*) all of the bronze surfaces were closely inspected. It was necessary to assess the extent of remedial treatment and repairs required to address the disfiguring corrosion as well as any material losses and structural damage. Fortunately, inspection revealed that reconstruction of parts of the statue was not necessary other than minor brazing repairs around the neck area (*Figure 5*).

Conservation commenced with cleaning of the bronze surface to remove deposits and loose corrosion products. The initial treatment was followed by controlled mechanical and chemical removal of adherent corrosion products. The tools employed included abrasive pads, scalpels, peening with glass micro-beads, high pressure water washing, and chemical treatment using chelating agents and an acid. The objective during the remediation process was to achieve a cohesive surface layer of cuprite (Cu_2O) whilst preserving as much of the stable bronze patina as possible.

2) Repatination of the bronze. Final repatination of the bronze statue was based upon documentation, aesthetic and functional aspects, in consultation with the conservators and public art and heritage personnel at Auckland Council.

3) Application of a protective coating. The final surface finish decided upon was hot application of microcrystalline wax comprising paraffin waxes. The temperature of the wax coating during application was kept in the range of 80°C to 100°C. Finally, a maintenance specification for the protective wax coating, particularly the ideal renewal time interval, was decided.

The conservation project on the Queen Victoria statue was very successful. The bronze statue is in very good condition to this day, in part due to the implementation of a regular maintenance program. As specified by the conservators, the bronze statue receives an annual re-application of a protective wax coating to maintain the desired patination on the bronze.

Corrosion issues on a modern wind sculpture

Kinetic art is a modern form of artwork made from any medium that contains movement perceivable by the viewer, or upon motion, for its effect. A wind sculpture installed next to a harbour comprised ten coloured poles, each with a pivoting cone reminiscent of wind socks. The cones spin, light up at night and make sound. The wind sculptures comprise ten painted galvanised steel poles six metres high, with the pole bases embedded in the ground or on the seashore (*Figure 7*).

Not long after installation cracking occurred in a weld on the grade 316L stainless steel support arm for the pivoting wind sock on one of the kinetic sculptures. The sculptures were subjected to wind velocities of 100 km/hour or higher and vibrate vigorously in the wind. The stainless steel pipe cracked at a weld adjacent to a pipe elbow on the U-shape support arm. The weld at the other end of the elbow on the support arm also showed cracking (*Figure 8*).

The kinetic sculptures were also exposed to a severe marine environment as well as high wind loadings. Chlorides from windborne sea salt (i.e. marine aerosol) gained access inside the support arm pipe during service. The pipe weld showed some lack of penetration across the throat of the weld and there was heat tint present on the stainless steel around the internal root of the weld. Heat tinting on stainless steel welds is undesirable as it encourages corrosion to occur on welds exposed to a corrosive environment. The cracking in the pipe weld was found to be due to a mechanism called chloride-stress corrosion cracking (SCC). Residual tensile stresses from fit-up and welding had contributed to the SCC.

Indications of fatigue were also observed on the stainless steel weld fracture face at high magnification in a scanning electron microscope (SEM). The cracking was likely assisted by fatigue due to cyclical loading on the sculpture support arm in wind. The cracking initiated at a notch at the root of the pipe weld where there was incomplete weld penetration. The notch and the presence of chlorides inside the stainless steel pipe arm supported an environmental cracking mechanism.

Designers generally know that grade 316L stainless steel is susceptible to stress corrosion cracking. Exposure of 316L stainless steel in a marine environment has to be managed through good design to ensure that cracking does not occur on vibrating parts. The lesson learned from this case was that when employing structural stainless steel components for modern outdoor sculptures an important feature prior to construction is to embrace good design including a welding procedure specification.

Corrosion problem on a lake sculpture

Large outdoor sculptures are sometimes staged in a sculpture park with artwork on display over many hectares of land. In an outdoor art collection, corrosion

Figure 7. Pole mounted wind sculptures located next to a harbour.

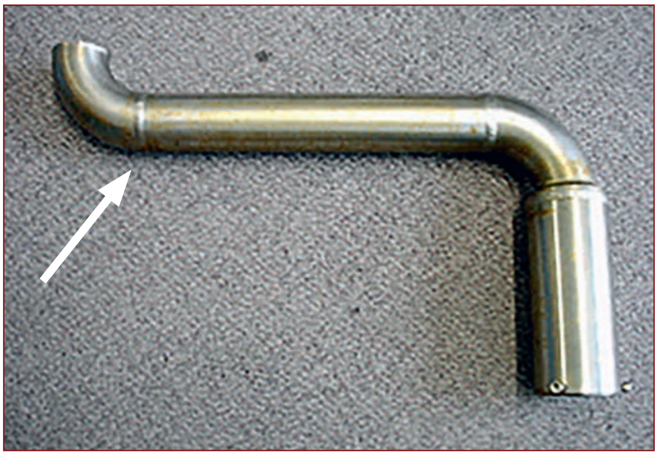

Figure 8. 316L stainless steel support pipe elbow on sculpture cone. Cracking occurred at pipe weld (arrowed).

occurred on the metal base of a hollow stainless steel sculpture that floated in a freshwater lake. The floating stainless steel sculpture was anchored to the lake bed (*Figure 9*). Corrosion of metal fixing components occurred adjacent to lifting lugs that formed part of the base of the floating artwork structure with its base submerged in the lake water.

The floating sculpture was fabricated from an unknown grade of stainless steel. There had been historic corrosion issues on the chain that secured the floating artwork to the heavy cast steel mooring on the lake bed. The steel mooring chain had been replaced with stainless steel chain and a magnesium anode attached to the chain to halt the galvanic corrosion occurring. However, the connections of the chain to the submerged base of the sculpture continued to corrode.

A sample of corrosion product from the submerged base component was submitted to X-ray analysis (EDS) in a scanning electron microscope, to identify the alloy employed for the connection. The analysis results indicated that the stainless steel component had undergone corrosion in the lake water. The grade of stainless steel employed appeared to be a free-machining ferritic stainless steel that contains a high sulphur addition. The grade of ferritic stainless steel employed for the base connection showed inadequate corrosion resistance submerged in the lake water. Free-machining grades of stainless steel have low corrosion resistance when exposed in a corrosive environment.

A higher grade stainless steel was required for the sculpture base component. The stainless steel employed for the sculpture base components and the mooring chain needed to be the same grade of stainless steel to avoid galvanic corrosion, that is, dissimilar metal corrosion between carbon steel and stainless steel. The use of an anode to provide cathodic protection to the steel mooring chain was unnecessary if the sculpture mooring connection components were all made from the same stainless steel alloy. Selection of grade 316L stainless steel was an appropriate choice for the component to attach the floating stainless steel sculpture base to the heavy cast steel mooring on the lake bed.

The lesson learned from this case was that appropriate grade selection of a stainless steel is most important to avoid problems when constructing a stainless steel outdoor sculpture. Selecting the correct grade of stainless steel for an outdoor environment is a key part of good stainless steel design.

Corrosion issues on a bronze sculpture located in a public domain

An outdoor artwork in a sculpture park at a public domain in Auckland was fabricated using cast silicon bronze and the sculpture comprised a set of modular bronze castings joined together. When installed in the sculpture park around 2005 the bronze had an attractive matt finish honey-gold colour. The artist wished to maintain the natural honey-gold colour of the polished bronze sculpture indefinitely without using any form of patination process.

Figure 10 shows the honey-gold colour on a cast test piece of the silicon bronze. For various reasons, the polished surface of the bronze sculpture had not been cleaned and coated with wax annually, as part of a maintenance plan. Wax is applied onto the bronze surfaces to stop the metal from coming into contact with an aggressive *marine aerosol* that prevails over the Auckland isthmus.

In 2010, the first clean and attempt to restore the honey-gold colour of the bronze sculpture took place.
The restoration work was completed with a two-coat waxing of the bronze surfaces. Prior to 2010 the bronze sculpture had developed a streaky surface appearance with what appeared to be 'rust spots' on areas of the bronze surface (*Figure 11*). Cleaning of the sculpture had taken place in winter and the cleans were impacted by the weather which delayed the conservation process; as a result the waxing was not carried out immediately after the sculpture cleaning.

Examination of the red-brown spots and streaks on the polished bronze surfaces confirmed that the deterioration of the bronze surface was likely due to contamination by minute particles of iron embedded in the bronze surface during the casting process. Alternatively, the surface contamination occurred when the castings were cleaned by shot-blasting at the foundry. The embedded iron particles had undergone galvanic corrosion in contact with the bronze on the sculpture surface. Iron oxide (red rust) was produced and the corrosion products weeped under gravity from spots on the bronze surface producing streaks that were aesthetically unpleasant.

It was important for the artist and Auckland Council Public Art to carry out some research to identify the most appropriate restoration method available before conservation work commenced. Fortunately, an unexposed sample of the original silicon bronze cast material, as a disc (*Figure 10*), was available for testing and research. The research program carried out on the bronze disc included (a) chemical analysis, (b) metallurgical examination of the bronze microstructure, (c) environmental exposure testing of the sample in a severe marine environment with different protective coatings applied onto the polished bronze surface.

Figure 9. Floating stainless steel sculpture moored in a fresh water lake at a sculpture park.

Figure 10. The honey-gold colour of a polished silicon bronze casting similar to the pieces comprising the sculpture.

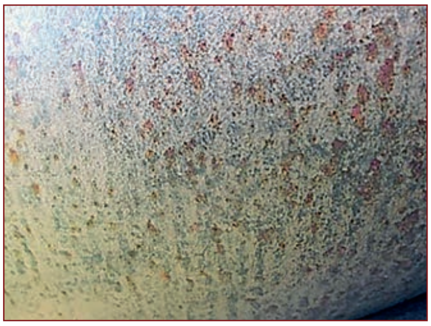

Figure 11. Rust spots and streaks that developed on the polished surfaces of the silicon bronze sculpture.

The composition of the bronze (XRF analysis) was found to be only slightly out of specification for alloy UNS C87600 (silicon bronze). The silicon bronze showed a slightly elevated level of iron (Fe) present. Metallurgical analysis also indicated that the surface of the silicon bronze casting contained a slightly elevated iron level; otherwise the cast silicon bronze microstructure was normal.

The surface of the bronze disc was polished and prepared for exposure testing. The bronze surface was polished by manual abrasion with ultra-fine silicon carbide pads. The surface finish achieved was better than on the actual bronze sculpture, as only light surface oxidation had to be removed from the bronze alloy. The polished surface of the bronze disc was cleaned and degreased. The polished disc was then masked off into four segments (quadrants). Each quadrant was treated with one of four different coating systems that were often used by conservators for bronze sculpture restoration in order to minimise atmospheric corrosion of the sculpture substrate.

The four segments on the bronze sample are shown in *Figure 12*. The identification marks, A, B, C and D, were chosen to identify each of the four coating systems that were subsequently applied. The quadrants on the bronze disc were treated as follows:

A: Application of 5% w/v benzotriazole (BTA; copper corrosion inhibitor) in ethanol followed by a hot microcrystalline wax application. Two further coats of wax were cold-applied.

B: Application of *Incralac* acrylic coating followed by two cold-applied coats of microcrystalline wax.

C: Cold application of *Fishoilene* corrosion prevention compound.

D: Hot application of microcrystalline wax with BTA incorporated into the wax. A second coat of wax was cold-applied.

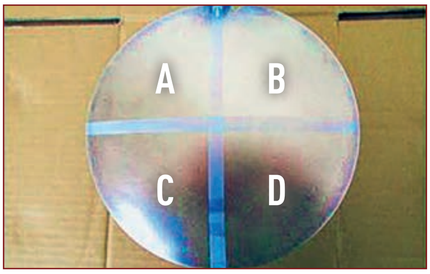

Figure 12. The silicon bronze cast disc after polishing, cleaning and masking into four segments.

Figure 13. The old dredge MV Rapaki *moored (right) at the National Maritime Museum wharf on Auckland harbour.*

Figure 14. The bronze disc mounted vertically on the dredge cabin.

Figure 15. The bronze disc after exposure to a severe marine environment for 3 months.

The bronze disc was exposed in a vertical orientation to the prevailing marine environment, attached to the cabin of an old dredge moored by a wharf at the National Maritime Museum in Auckland. The dredge was situated on the edge of Auckland harbour (*Figure 13*). The bronze disc was installed facing north-east and the sample was rain washed during the exposure period. The exposure time in the marine environment on the dredge was approximately three months. The bronze disc was removed and swabs of visible corrosion products were taken off each quadrant. The swab samples were subjected to microscopic examination and to X-ray analysis (EDS) of the corrosion products in a scanning electron microscope.

After the examination, the segment on the bronze disc that performed best with least surface corrosion on the polished bronze surface was Sample B, the *Incralac* coating with two additional coats of wax. The second best surface treatment, with slight corrosion occurring on the bronze surface, was Sample C, *Fishoilene*. The remaining two treatments had the highest surface corrosion on the polished bronze, and corrosion performance results about the same, namely Samples A and D coated with microcrystalline wax plus BTA.

The results of the short term exposure testing of the four coatings on the bronze sample on the dredge demonstrated that the *Incralac* plus wax protective coating was superior to the other three coating systems tested. The results were somewhat surprising, because application of wax plus BTA has been recommended by conservators for protection of outdoor bronze sculptures for many years.

After the research was completed the Public Art managers were advised of the following recommended process for restoration of the honey-gold colour on the silicon bronze sculpture. Correct logistics were noted to be critical to the success of the bronze sculpture refurbishment.

Initially the bronze sculpture should be cleaned and mildly blasted (walnut shell) to remove any surface residues and corrosion products. After blasting the sculpture should be cleaned immediately with non-ionic detergent solution and rinsed with clean water to remove the detergent residues. Following water rinsing the sculpture surfaces should be cleaned with a solvent (e.g. white spirits) to remove the last traces of any surface residues off the bronze surfaces.

A full even coat of *Incralac* should be sprayed onto the cleaned sculpture surfaces. The applicator should follow the recommendations of the manufacturer for the application and drying time of the *Incralac* coating. Once the *Incralac* coating has fully cured, apply two cold coats of microcrystalline wax. The first wax coating should be lightly buffed with soft cotton pads before the second wax coating is applied. The second wax coating should be gently buffed after application.

The application of a new wax coating should be undertaken annually as a protective coating on *Incralac*. The waxing is necessary to ensure that the prevailing marine atmosphere does not cause deterioration of the acrylic coating on the bronze. During maintenance and re-waxing of the sculpture it is important to ensure that the wax coating on the sculpture is not cleaned with a solvent. Solvents can have a deleterious effect on an *Incralac* coating. The wax-coated bronze sculpture surface should be periodically washed with clean water to remove any surface contaminants.

The exposure testing and research on the silicon bronze sample that was carried out provided the sculpture park managers with a basis for restoring and protecting the polished silicon bronze sculpture against atmospheric corrosion in the prevailing marine environment.

Conclusions

Corrosion issues arise on outdoor public art from time to time which require investigation and remedial actions to be taken as advised by conservation specialists. Conservators are professionally trained to carry out conservation and restoration processes on public art using established scientifically based remediation methodologies.

The occurrence of a failure on an outdoor art object due to an unexpected engineering problem requires an immediate response and appropriate remediation work to be implemented.

Conservation, restoration and maintenance of outdoor public art make an important contribution to a community.

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Presented at C&P2015 Conference

Structural Risk Assessment of Corroding Infrastructure

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It is important to understand the difference between structural risk and corrosion risk. Corrosion risk usually is associated with the notion that there is a probability that corrosion might occur and the extent to which it might occur. The term corrosion risk is used often in the corrosion literature and has been used so for a long time. Examples include the risk of pitting corrosion, or crevice corrosion [1]. Typically it is measured by the number of times there are signs of pitting (or crevices) on defined surface areas. However, the occurrence of such corrosion need not have a significant effect on structural risk; that is the risk or probability of significant structural failure or service impairment. In the following, illustrations are given of cases in which corrosion occurred, but there was little or no probability of structural failure. There are of course other cases where serious corrosion occurred and the structural risk was high.

The term risk is often confused with probability and with the consequences that arise from a possible risk scenario. It is useful, therefore, to review briefly the terms involved. Risk is defined by ISO31000:2009 Risk Management – Principles and Guidelines [2] as the *effect of uncertainty of objectives*. There are many varying aspects of risk which include financial, health, safety and the environment. These can be applied on a number of levels such as strategic, organisation-wide, project, product and process. Risk is often characterised by reference to potential events and consequences, or a combination of such. Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence [2].

Stewart and Melchers [3] note that the term risk is commonly interchanged with words like chance, likelihood and probability, all to indicate that we are uncertain about the state of the item, issue or activity under discussion. They discuss that a more formal definition of risk includes dependency on both probability and consequence. On this basis, a risk-based decision analysis can be presented as in the flow chart shown in in Figure 1.

ISO55000:2014 Asset Management – Overview, Principles and Terminology [4] is linked to ISO31000:2009 [2]. ISO55000:2014 [4] states effective control and governance of assets by

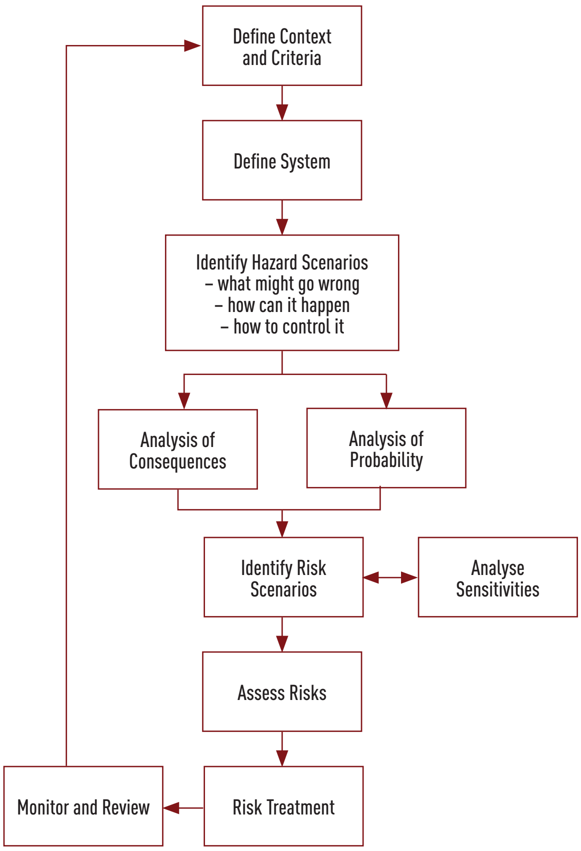

Figure 1. Flow chart for decision analysis [3].

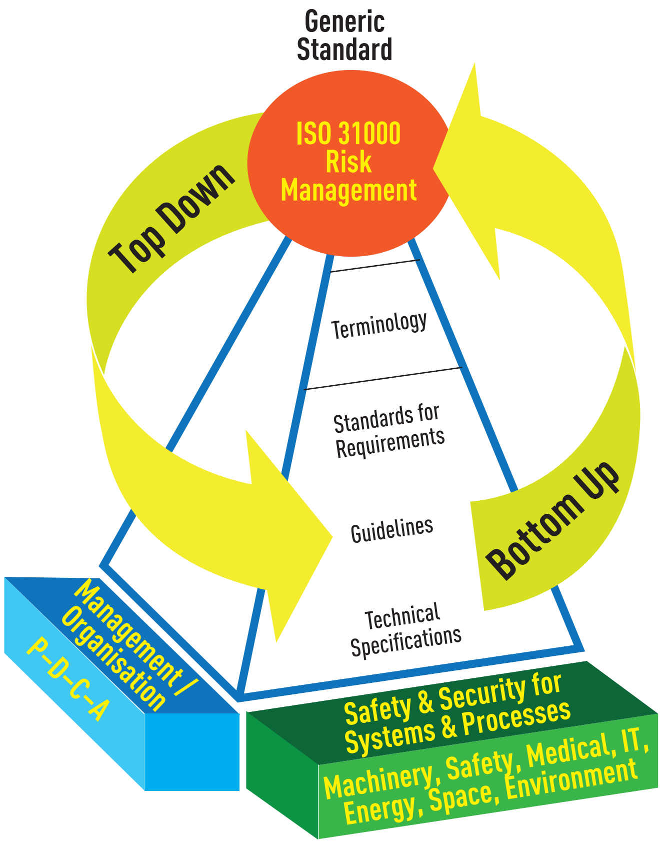

Figure 2. Approach of the planned generic standard on risk management [5].

organisations is essential to realise value through managing risk and opportunity, in order to achieve the desired balance of cost, risk and performance. The regulatory and legislative environment in which organisations operate is increasingly challenging and the inherit risks that many assets present are constantly evolving. Asset owners need to be able to manage the risk of their assets on a variety of levels. This paper explores the options of achieving this through the difference of structural risk and corrosion risk.

Berg [5] developed an approach which illustrates how and where ISO31000:2009 [2] applies. It is shown in Figure 2.

ASSESSMENT METHODOLOGY

Asset managers, infrastructure owners and stakeholders normally indicate a remaining service life requirement for their assets. To achieve this, useful conclusions and recommendations are necessary to allow the asset owner to act on the observations and findings discovered during any assessment. To develop meaningful conclusions and recommendations it is important to follow a specific process and procedure appropriate for the asset type and location. These should include but be not limited to, inspections, desktop structural assessments, targeted detailed inspections and field testing as a result of the desktop assessment, and remediation scopes as required.

The fundamental basis of assessment process is the inspection of the asset under consideration; if the inspection is undertaken in accordance with the generally accepted applicable guidelines and standards and done so by a suitably qualified and suitably experienced person then it can be expected that the conclusions and recommendations drawn from the assessment will generally be appropriate. Inspection guidelines available in the roads and bridges sector, (i.e. VicRoads Road Structures Inspection Manual [6], RTA Bridge Inspection Procedure Manual [7], and Queensland Department of Main Roads – Bridge Inspection Manual [8]) all recognise the necessity for the inspecting person(s) to be appropriately qualified, experienced and competent to ensure suitable recommendations are determined, which then enable asset owners to make informed decisions regarding asset maintenance. This indicates that these asset owners and custodians consider this to be a vital requirement of the assessment. This however, may not be the case for other sectors (i.e. mining, port authorities, etc.) where in some cases inspections currently are being undertaken by inexperienced personnel. This lack of experience and fundamental understanding of structural behaviour such as load paths may result in critical members being overlooked during inspections and ultimately result in catastrophic failure.

Desktop structural assessments, (pre and / or post inspection) provide meaningful outcomes that enable targeted future inspection guidelines to assist with inspections and any further assessment. The desktop structural assessment may involve, but not be limited to, Finite Element Analysis (FEA) of the as-new structure with scenario analysis to confirm structural redundancy magnitudes, (if any) for asset elements (i.e. what corrosion can be afforded, if any, to individual members). This therefore provides guidelines regarding tolerable structural losses for future inspections. This assessment can be utilised with site inspection findings to determine risks for the asset and suitable timing (and nature) of repair and / or strengthening remedial works together with any ongoing inspection requirements.

Desktop assessments enable a targeted approach to field-testing. Field-testing could be in the form of visual inspection, non-destructive testing (NDT), invasive testing, and field mapping and sampling, depending on the type of asset being considered and the potential risks involved.

The Five Step Approach outlined by DNV [9] lists the steps required during an assessment process in accordance with ISO31000:2009 [2]. The steps are as follows;

1. Pre-assessment,
2. Screening and risk ranking,
3. Detailed examination,
4. Remediation and repair, and
5. Life cycle management.

These steps follow the basis of what has been discussed previously, and what has been undertaken throughout the case studies that follow.

CASE STUDIES

To illustrate the functionality and practicality of the assessment methodology outlined above, and in particular the benefit of structural auditing practices, a number of case studies are described in brief below together with the comments that confirm the benefit to clients.

Coal Handling Facility

An aging coal handling facility located within a port on the east coast of Australia has experienced structural failures to some of its elevated conveyor gantries and coal storage surge bins. These failures were as a direct result of corrosion based deterioration to critical members. Auditing of the structures by inexperienced personnel had not identified the criticality of the corrosion that had occurred to some components, and this led the asset owner to conclude that the current site inspection techniques and risk assessment methods were inadequate. The asset owner initiated a structural audit investigation, including site inspections and desktop structural assessments. These were undertaken by suitably experienced structural engineers, to gain an initial appreciation of the extent and location of corroded areas of the operational elevated gantries and surge bins.

The conveyor gantries generally comprise two parallel chord trusses (at the side faces) connected by roof and floor tie beams and bracing elements with floor plate spanning the full width between bottom chords. The gantries are in turn supported by transfer towers / surge bins or trestles and they vary in length and span up to 30 metres (m). The construction of these gantries is considered to be light, with some non-conformances in design being identified by the desktop structural assessment. Some typical observations from the gantry structural audit are shown in Figures 3 and 4.

Figure 3. Failed top chord gantry compression member due to buckling at corroded area.

Figure 4. Corrosion to walkway floor plate, namely the heat affected zones, leading to perforations.

The coal storage surge bins consist of external columns, tie beams and bracing elements, as well as horizontal ring beams and vertical trimmer beams which support the internal bin and hopper elements utilised for coal storage. Elevated conveyor gantries feed coal into the top of the structure and conveyors at ground level carry coal away from the bins and hoppers. These surge bin structures range in height from 18m to 39m with an external lift structure used for access. Some typical examples of the findings from the surge bin structural audit are shown in Figures 5 and 6.

Figure 5. Heavily corroded and perforated bin wall plate element.

Figure 6. Column base plate has lost a large amount of section. Previous repair (coating only) inadequate.

As shown in these figures, corrosion had initiated and therefore could pose a risk to the coal handling facilities structural adequacy. In order to determine the structural risk associated with the site observations / findings, a desktop structural assessment was necessary. Outcomes from the desktop assessment together with site findings were utilised to prioritise and scope a programme of works for remedial repair and strengthening works.

The failures observed together with the audit inspection outcomes identified and confirmed that the current site inspection techniques and risk assessment methods were inadequate. Inspection methods and techniques that required improvement included suitable qualifications / experience of inspectors, inspection scope, understanding of structural redundancy and load paths, when and where NDT should be utilised and how site inspection data outcomes could be used with desktop information to trigger appropriate repairs and maintenance actions.

Therefore structural risk determined in accordance with inspections undertaken by qualified and experienced people and input from desktop assessments, is not the same as corrosion risk. Furthermore the cost of unforeseen structural failure or unforeseen remediation (that may also include consequential operational or non-production costs) can be many orders of magnitude greater than the difference in cost between using suitably experienced and qualified assessors versus inexperienced assessors.

Concrete Water Reservoirs

Concrete water reservoirs are common in the water industry and are utilised as water storage in systems that supply potable water to millions of people. Many potential failure mechanisms have been identified from experience with these structures and they depend on the structural arrangement, soil support conditions, durability of materials, etc. A general visual inspection of concrete water reservoirs in both Queensland and Tasmania by their respective operators identified the failure of vertical post-tensioned wall reinforcement [9]. The possibility of these failures, due to corrosion of the steel, had not been identified in any risk assessment or management plan. The present case study arose from an independent assessment and considers the failure of un-grouted post-tensioned vertical stressing bars within the reservoir's wall.

Due to the large amount of stress applied to these post-tensioned bars, it was established by independent testing that the failure mechanism was stress corrosion cracking (SCC) with the cracking initiating at corrosion pits at the base of pre-existing micro-cracks. Examples of the failed vertical stressing bars are shown in Figures 7 and 8.

Figure 7. Failed vertical stressing bar of a 50ML reservoir located in the central coastal area of Queensland.

Figure 8 Failed vertical stressing bar from an approximately 3ML reservoir located on the North Coast of Tasmania.

From these failures it is evident that there is a corrosion risk associated with un-grouted vertical stressing bars. Does this translate to a structural risk? In the case of the 50ML reservoir in Figure 7, the answer clearly is 'yes'. This reservoir is located directly above a residential area posing an extreme risk with severe safety and financial consequences if failure was to occur.

A preliminary desktop structural assessment utilising FEA was undertaken to determine likelihood of further failures. Contingency plans were developed to lower water levels in the interim until wall repairs/ strengthening utilising appropriately designed and installed carbon fibre laminate. Improvements were developed and implemented regarding grouting the small annulus surrounding the bars to enhance corrosion protection together with a monitoring regime. This enabled a return to normal operations.

This case study also indicated misgivings in the ongoing inspection and risk management processes of these assets. It was only the desktop structural assessment, combined with detailed site and materials investigation (by appropriately experienced personnel) that allowed the risk assessment for varying scenarios (including do nothing) to be established. Outcomes of the risk assessment then allowed for the maintenance and asset management strategy to be established and adopted. This showed the importance of the fundamental understanding of structural risk determined in accordance with inspections undertaken by qualified and experienced people and input from desktop assessments, and that this is not the same as corrosion risk. The case study also illustrates the need to understand corrosion risk (e.g. SCC) using suitably qualified and experienced people in conjunction with a sound laboratory assessment.

Coal Storage Silos

Two 3000-tonne capacity reinforced concrete coal silos and one 5000-tonne capacity reinforced concrete silo in the Hunter Valley, New South Wales were critical assets necessary to facilitate the efficient delivery of coal for export [10]. Serious concrete deterioration of the silos and corrosion to external post-tensioned cables had the potential to catastrophically interrupt the coal supply chain. After the failure of some of the existing external post-tensioned cables (falling some 20m to the ground) a desktop structural assessment, condition investigation and risk assessment of the silos was undertaken.

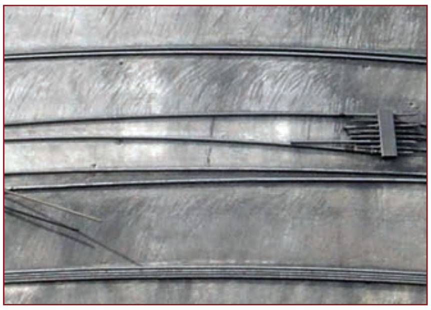

Figure 9. Failed post-tensioned cables on silos.

Figure 10. Corrosion to post-tensioned cables.

The desktop structural assessment incorporating a 3D FEA model, established that the enhancement of strength offered by the post tensioned cables is paramount and that their effective strength capacity needed to be restored. However, further strengthening was also required due to vertical bending near the silo floor, as sway of the silo under temperature and high shear loads had caused cracking to the lower dividing shear walls. The condition investigation identified that concrete compressive strengths were adequate and reinforcement corrosion activity was concentrated at crack locations greater than 0.5mm wide and at low concrete cover areas due to the depth of carbonation. A remedial option scenario analysis with a risk assessment was conducted, with the outcome being that carbon fibre laminates (CFL) applied externally (vertically and horizontally) in a staged manner to allow restricted operations (during remediation) to continue. CFL was applied only after zones of unacceptable concrete (carbonated, delaminated and or widely cracked) were removed and repaired with a sprayed cementitious polymer modified repair mortar. An elastomeric anti-carbonation coating system was then applied to external silo concrete surfaces. The capacity of the silos was fully restored, service life has been extended to the required 25 years and safety has been enhanced at the site.

This case study again illustrates the uncertainties in the ongoing inspection and risk management processes of these critical assets. The failure of the external post-tensioned cables indicated that current site inspection practices were not effective. Practices identified that required improvement included; suitable qualifications / experience of inspectors for varying tiered inspection requirements and an inspection scope. The structural assessment allowed a targeted approach to repair, maintenance and asset management strategy to be established and adopted.

This example confirms that structural risk determined in accordance with inspections undertaken by qualified and experienced people and input from desktop assessments, is not the same as corrosion risk.

Pedestrian Footbridge

Pedestrian footbridges are utilised world-wide to enable pedestrians to safely cross highly trafficked areas such as roads, highways, and in this case a rail corridor. This particular rail corridor services both coal trains and cargo trains in and out of a busy port located on the east coast of Australia. The pedestrian footbridge allows public access to an area of the harbour which is used for recreational activities. The footbridge is approximately 100m long and is supported at regular intervals by trestles. The scheduled 6 monthly inspection of the footbridge found heightened levels of corrosion to steel sub-structure elements and deterioration to the reinforced concrete elements (i.e. spalled and delaminated concrete exposing low cover corroding reinforcement). Corrosion of the steel sub-structure elements was predominately localised in sheltered areas due to the high deposition of salts without any rain wash-down of the surfaces of these sheltered structural elements. Some typical examples of the findings from the investigation are shown in Figures 11 and 12.

Figure 11 Heavy corrosion to walkway slab support beams.

Figure 12. Walkway slab edge spalling and delamination.

Following the initial inspection, remedial work scenarios were developed and provided to the asset owner for consideration. If no repairs were to be undertaken a remaining service life of up to 2 years was advised to the asset owner with the provision of further inspections at 6 monthly intervals. If the concrete walkway was repaired and / or replaced an estimated service life of the entire footbridge of up to 5 to 10 years was achievable. After 5 years the steel framework of the bridge will require steel fabrication repairs together with maintenance and reapplication of a protective coating system. If the above two items are addressed then the footbridge will require ongoing maintenance at a frequency of every 10 to 15 years.

The asset owner considered the inspections of the footbridge paramount and therefore used a qualified and experienced structural engineer, which enabled a remaining service life to be estimated. This is similar to the VicRoads [6] and Queensland Department of Main Roads [8] inspection manuals which have a requirement for inspectors to be appropriately experienced and competent for the inspection. This acknowledges the importance of recognising structural risk determined in accordance with inspections undertaken by qualified and experienced people and input from desktop assessments, and this is not the same as corrosion risk.

It can also be concluded that the owners of this asset had previously used inexperienced assessors and then only used those suitably experienced and qualified when they perceived a higher and unacceptable level of risk. Therefore it could be argued a suitable process was instigated by the experienced assessor (with asset owners support) only after the asset owner was not comfortable with the perceived level of risk.

Steel Sheet Pile Walls

A working harbour on the east coast of Australia has a number of steel sheet pile walls surrounding its banks. There have been a number of failures to these sheet pile walls through varying mechanisms causing the asset owner unexpected costs and lost time.

The first wall failed due to the corrosion of the land tie fixings to the sheet pile wall on the seaward side. These fixings are located in both the splash zone and tidal zone. The failure occurred due to corrosion and subsequent section loss to a number of land tie fasteners connected to the waler beam. Figure 13 shows the section of failed sheet pile wall and Figure 14 shows the extent of deterioration to the remaining land tie fasteners.

Figure 13. Failed sheet pile wall.

Figure 14. Corroded land tie fastener.

Similar to the footbridge discussed previously, a series of remedial work scenarios were provided to the asset owner. A do nothing approach provided an extreme risk and was immediately discounted. A full replacement option was also discussed, as well as two repair methods to achieve an estimated service life of 15 years and 25 – 50 years, which all reduced the risk significantly from an extreme to a moderate rating. The option which was adopted was to install a rock revetment which was a cost effective solution as well as reducing the risk to the asset owner.

This case can be seen to revert back to current site inspection practices being ineffective, similar to the case study at the coal handling facility. The need for suitably qualified inspectors with a detailed inspection scope and frequency of inspections is paramount in providing the required data to asset owners, enabling a considered and measured approach when determining repairs and maintenance actions as opposed to reactive remedial repairs which are costly and unable to be planned.

Another steel sheet pile wall, in the same harbour as above was also investigated. Initial above water inspections produced findings typical of Accelerated Low Water Corrosion (ALWC) and Microbiological Influenced Corrosion (MIC) [12, 13, 14]. A second underwater inspection with focused diagnostic testing (with the aid of divers) was then commissioned and the ALWC and MIC was confirmed at localised locations along the sheet pile wall. Figure 15 provides an above water photo of the sheet pile wall, and Figure 16 is a typical area of corrosion principally due to MIC. The reliance on commercial divers also points to an operational weakness of the inspection teams and hence an additional risk. If the experienced corrosion engineers became qualified scientific divers (or view divers observations directly by using suitable technology) they could apply their detailed knowledge directly during the underwater inspection program.

Figure 15. Above water view of sheet pile wall.

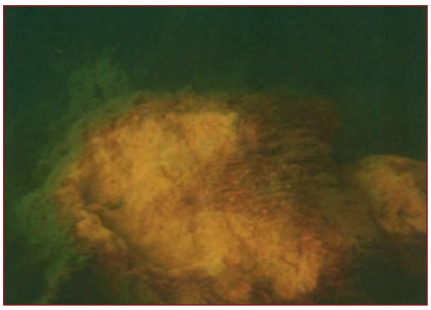

Figure 16. Typical area of MIC.

From the secondary inspection and thickness testing readings a desktop structural assessment with sensitivity variations was able to be undertaken to confirm the structural utilisation and tolerable section loss. Remedial option scenario analyses were presented included do nothing, replacement of the wall, and monitor and locally repair as required. As the corrosion was captured early through the inspections the asset owner was able to adopt the approach of monitor and locally repair the wall as required. This was a very cost effective outcome and reduced the risk to an acceptable level for the asset owner.

This again comes back to the need for qualified inspectors with a detailed inspection scope and frequency of inspections. The other implication of these case studies points towards the need to upgrade the appropriate standards through a more rigorous pre-qualification process. The corrosion and section loss to the wall was able to be detected early and with the aid of a desktop study the risk was able to be mitigated through ongoing monitoring and local patch repairs as required.

This example confirms that structural risk determined in accordance with inspections undertaken by qualified and experienced people and input from desktop assessments, is not the same as corrosion risk.

Concrete Dolphin Wharf

A working harbour on the east coast of Australia has a number of dolphin wharf structures which are utilised for the mooring of vessels. This particular concrete dolphin had experienced significant corrosion to the steel piles and the reinforcement contained within the concrete components of the structure. The deterioration was observed by the asset owner and hence a consultant was engaged to determine the requirements for the continuation of its use.

Initial inspections found varying degrees of corrosion in the steel elements and different degrees of cracking in the concrete elements. It was determined that a desktop structural assessment of the structure was required to confirm the remaining capacity of the structure. Figures 17 and 18 show typical examples of the defects observed on the dolphin wharf.

Figure 17. Delaminated concrete with heavily corroded reinforcing bars exposed.

Figure 18. A crack at the edges / soffit of a dolphin structure.

From initial inspections it was evident that the corrosion was active, however the structural risk was unknown. The paper from Ports Australia [15] is targeted towards the condition assessment of wharves and draws a relationship from condition state to remaining service life. According to this philosophy, the dolphin wharf structure discussed falls between the condition states 6 and 7, which indicates rehabilitation required, renewal required immediately, or replace member / asset immediately [15]. Figure 9 in the Ports Australia paper [15] indicates this dolphin has 0 to 10% service life remaining and according to the paper needs to be rehabilitated or replaced immediately. Keeping this in mind, from the detailed desktop structural assessment undertaken it was determined that the as-new structure had a level of redundancy. Taking into account the current level of dilapidation of the structure, with minor repairs it was determined that this structure has a remaining service life of between 10 to 25 years, subject to the level of commitment to ongoing maintenance. This is not consistent with what Ports Australia [15] have concluded; assuming a 50 year service, this dolphin would only have between 0 and 5 years remaining service life. This illustrates that corrosion risk and structural risk are not the same.

This case study shows that structural risk determined in accordance with inspections undertaken by qualified and experienced people and input from desktop assessments, is not the same as corrosion risk.

CONCLUSIONS

ISO31000:2009 [2] provides a framework to providing risk management, which is referenced and required through the utilisation of ISO55000:2014 [4]. Asset owners need to be aware of these Standards and should conform to their requirements to ensure that asset risks are adequately managed.

With the current condition of aging assets an industry prepared and accepted set of corrosion based inspection guidelines appears to be beneficial to allow asset owners to manage their assets and trigger the appropriate actions. However, qualified and experienced inspection persons are required to undertake the inspections to ensure due consideration of the structural behaviour, redundancy and load path to ensure the identification of critical members.

Desktop structural assessments allow the structural risk of assets to be adequately managed, as well as determining a remaining service life for the structure.

From the example case studies outlined in this paper it is evident that structural risk is not the same as corrosion risk. It is a message relevant for asset managers and engineers, but also for corrosion professionals [16]. It is highly desirable that key elements of this paper are incorporated into tertiary training programs and on-line instruction manuals.

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Who Rusts First: Revisiting Galvanic Corrosion

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1. Introduction

Galvanic (or bimetallic) corrosion arises when dissimilar metals are electrically connected in a common electrolyte. The more active (or anodic or electronegative) metal will corrode or oxidise. Electrons from the oxidation reaction travel to the more noble (or cathodic or electropositive) metal. Electrons are taken up by a reduction reaction, usually oxygen and water forming hydroxyl ions at the cathode. The basic parts of the galvanic cell are shown schematically in Figure 1. While galvanic corrosion is readily explained and understood, it is often wrongly interpreted to mean that it will arise whenever dissimilar metals are joined. In practice, the severity of the galvanic action depends on factors such as:

- Electrochemical difference between the two metals
- Area of the two metals
- Nature of the cathodic surface
- Nature of the electrolyte

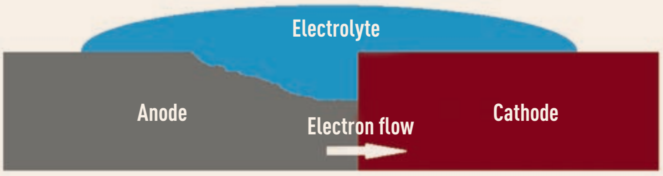

Figure 1: Basic principle of galvanic corrosion.

This paper looks at the practical aspects of galvanic corrosion, and how these and other factors influence actual behaviour. First, a little history.

2. History

The main breakthroughs in galvanic corrosion and its understanding were:

- 1786 – Luigi Galvani in Bologna observed the twitching of a frog's leg on a steel plate when it touched a brass hook connected to the nerves. He wrongly concluded that the frog's leg muscle had twitched because it stored electrical charge.

- 1792 – Alessandro Volta in Pavia repeated Galvani's experiments and found electrical current came from the dissimilar metals, not the frog. He carried out experiments on different combinations of metals and found which pairing produced greatest "electromotive force". The combination of zinc and silver seemed to offer best results.

- 1801– Humphrey Davy in London proved that electricity and chemical affinity are identical and refined and expanded Volta's work. In a presentation to the Royal Institution, he produced what is probably the first Galvanic Series, shown in Figure 2, "in which the different substances are arranged according to the order of their known galvanic powers, [and] will shew [sic] how intimately chemical agencies are related to the production of galvanism."(1)

TABLE OF SOME GALVANIC CIRCLES,

COMPOSED OF TWO PERFECT CONDUCTORS AND ONE IMPERFECT CONDUCTOR.

More oxydable substances.	Less oxydable substances.	Oxydating fluids.
Zinc...	With gold, charcoal, silver, copper, tin, iron, mercury.	Solutions of nitric acid in water, of muriatic acid and sulphuric acid, &c. Water holding in solution oxygen, atmospheric air, &c.
Iron...	—— gold, charcoal, silver, copper, tin.	
Tin ...	—— gold, silver, charcoal.	
Lead ..	—— gold, silver.	Solution of nitrate of silver and mercury. Nitric acid, acetous acid.
Copper.	—— gold, silver.	
Silver..	—— gold.	Nitric acid.

Figure 2: Humphry Davy's chart of "Galvanic Circles".

- 1820 on – While galvanic action between two metals was relatively easy to study and understand, investigation of the electrochemical behaviour of a single metal was more difficult. In Sweden, Jons Berzelius studied how various atoms migrated to either the positive or negative pole in a solution electrolysed by a voltaic pile and prepared the first "Electrochemical Series". With the development of reference electrodes in the late 1800s, Wilhelm Ostwald noted electrode potential was a measure of oxidising or reducing power and was able to develop a table showing actual potential differences between metals and their salts, the precursor to the Electrochemical or Electromotive Force (EMF) Series used by chemists today.

- 1918 – Bauer and Vogel (2) in Berlin looked at corrosion between iron and a second metal, measuring the amount of corrosion of each metal in the couple. Their results are plotted in Figure 3. They showed iron is protected by contact with an anodic metal, and corroded by contact with a more noble metal, as expected. But they also noted that the amount of corrosion of the steel as a result of contact with a more noble metal is approximately identical (170-180g), regardless of the metal, although the amount of corrosion on an active metal protecting the steel varies considerably.

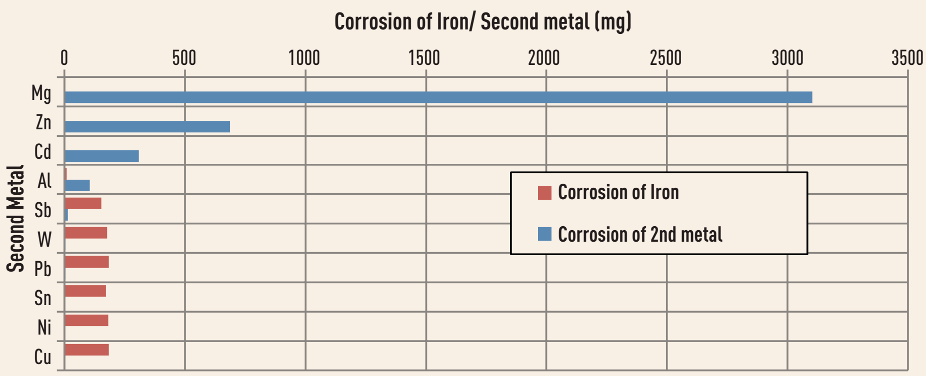

Figure 3: Bimetallic corrosion of iron and a second metal in 1% NaCl solution (2).

3. Effect of Electrochemical Potential

The potential developed on a metal surface is the first and most important consideration determining the extent of galvanic corrosion. If a metal is placed in a solution, there will be a tendency for metal atoms to oxidise to ions and go into solution or conversely for ions to plate out on a metal surface. This tendency will create a potential difference (or voltage) between the metal and the solution at the surface of the metal. There is, however, no practical method of evaluating the absolute magnitude of this potential difference since completing the electrical circuit to measure the potential would introduce a second metal/ solution interface with a second unknown potential difference. So instead, the relative potential is measured against a reference electrode. Potential measurements can and have been carried out in many environments, but sea water at room temperature is the most common. A number of reference electrodes have been used, with the saturated calomel electrode is most common. The chart shown in Figure 4 is one of the most common and widely available Galvanic Series and found in books, papers and web sites. Other published lists give similar results, although most others show lead and tin are somewhat more active (more negative). Newer alloys such as duplex and super austenitic stainless steel have potentials of approximately 0.0 volts on this scale. Most metals do not give a single potential due to experimental errors and composition variations but rather show a potential range of 100mV or so.

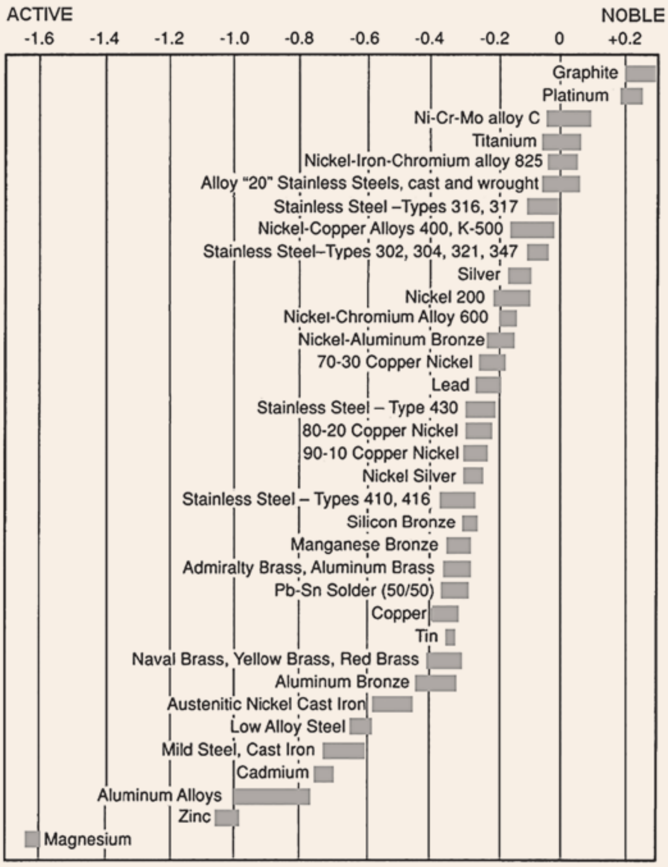

Figure 4: Galvanic series showing potential versus the saturated calomel reference electrode developed in flowing seawater.

As mentioned above, when two metals from the galvanic series are electrically connected in a common electrolyte, the more active metal of the joined couple will corrode while the more noble metal becomes the cathode. Electrons will flow from the anode to cathode, the potential at the anode-cathode junction becomes the corrosion potential once equilibrium is achieved and the corrosion current density is directly related to corrosion rate by Faraday's Laws of Electrolysis. The current that flows between two metals should therefore give a more accurate indication of the severity of galvanic corrosion and such measurements using a zero resistance ammeter are widely used in galvanic corrosion studies.

AS 4036 (3) has a table produced using such current measurements which indicate the level of corrosion that can be expected when certain metals are in contact with a second metal. The results are based on galvanic current tests lasting 28 days in artificial seawater. The additional corrosion on a 'metal considered' when joined to a second 'contact metal' is given one of four ratings, depending on the current flowing between them:

Rating A — Good The metal considered will be protected, unaffected, or suffer very slight additional corrosion as the result of contact with the contact metal. Any slight resultant corrosion is usually tolerable in service.

Rating B — Fair The metal considered will suffer slight, or moderate, additional corrosion as the result of contact with the contact metal. This amount of corrosion may be tolerable in some circumstances.

Rating C — Poor The metal considered may suffer relatively severe additional corrosion as the result of contact with the contact metal, and protective measures will usually be necessary.

Rating D — Very poor The metal considered may suffer severe additional corrosion as the result of contact with the contact metal and this metal combination is inadvisable even in mild conditions.

Of the 243 couples studied, 143 or about 60% were rrated A and 49 or 20% rated D. Going on these results, joining a second metal is not likely to cause galvanic corrosion and there is a only a one in 5 chance of severe galvanic corrosion. Clearly the idea that connecting a second metal always causes galvanic corrosion is incorrect. But the risk is not trivial and the worth looking at more closely. Figure 5 shows a number of metals from the Galvanic Series in Figure 4, with a colour rating in the first column for each metal indicating the potential difference. Yellow to green means increasingly protected, yellow to red increasingly corroded. The second column for each metal shows the AS 4036 rating for the metal couples that were tested, using a similar colour rating. For example, the first row of the table shows a contact metal connected to zinc (metal considered) will be more cathodic by about 0.3 to 1.0 volts moving from aluminium to Incoloy 825, so will be expected to cause corrosion of the zinc. The current flow testing shows that the zinc will suffer additional corrosion when connected to all contact metals. Other metals are evaluated similarly.

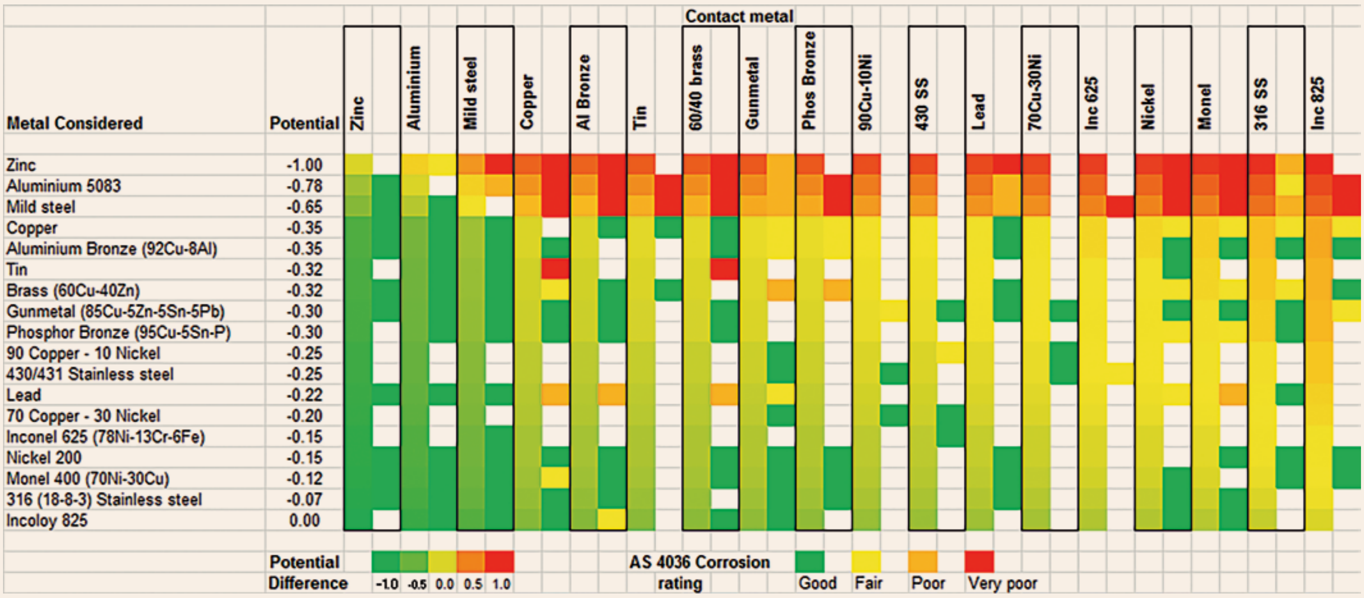

Figure 5: Potential difference from Figure 4 and AS 4036 galvanic corrosion rating for metal couples

The ratings given in AS 4036 can be compared with the potential difference between two metals to determine the minimum that can cause galvanic corrosion. Figure 6 shows the extent of additional corrosion as a function of the difference in potential, using the average potentials given in Figure 4. This shows some interesting findings:

- In general, the greater the potential difference between the two metals, the greater the amount of additional corrosion on the anode. However, this observation is only a general trend and does hide some important anomalies.

- It is possible to join two metals with a potential difference of approximately 350 mV, without having significant extra corrosion. As an extreme, only minor additional corrosion is observed on aluminium when joined to 316 stainless steel (green circle), despite the two metals being over 700 mV apart on the Galvanic Series.

- Although severe additional corrosion usually requires a difference in of at least 350 mV, some couples tested show galvanic corrosion with only a small difference. For example, tin suffers severe additional corrosion when connected to brass or copper, despite little difference in potential (red circle). Lead suffers some additional corrosion when connected to metals only 100 to 150 mV different. (These observations seem to confirm that tin and lead are more active than the Galvanic Series in Figure 4 suggests).

In summary, analysis of the ratings given in AS 4036 shows that, of the couples studied:

- Zinc will corrode significantly if connected to any more cathodic metal except aluminium, which results in only minor additional corrosion.

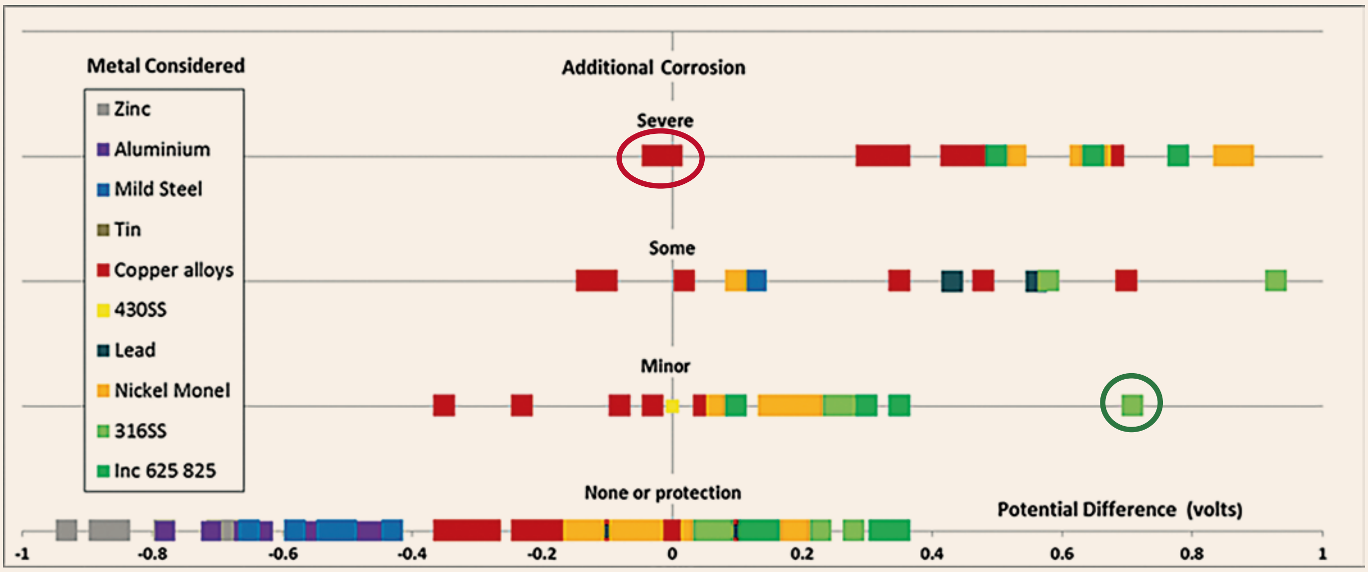

Figure 6: Extent of additional corrosion according to AS 4036 as a function of difference in potential according to the Galvanic Series inFigure 4.

- Similarly, aluminium will corrode if connected to any more cathodic metal. However, 316 stainless will cause only minor additional corrosion with this metal.

- Mild steel suffers additional corrosion connected to any more cathodic metal.

- Tin suffers severe corrosion when connected to copper and nickel alloys.

- Lead connected to copper and nickel alloys will suffer some additional corrosion. However, it does perform satisfactorily with 316 stainless steel.

- Copper, nickel, stainless and chromium/iron alloys are generally acceptable when connected to each other under these conditions.

This absence of a direct relationship between potential difference and current has also been established by other investigators. For example, Mansfeld and Kenkel (4) investigated some 95 galvanic couples with various aluminium alloys as one of the metals and also found only a general relationship between galvanic current density and difference in uncoupled corrosion potentials. Again, they found a low galvanic current is possible with significant potential difference and vice versa. Steel, copper and silver had the most severe galvanic effect on aluminium with stainless steels and titanium having much less effect, despite significant potential differences.

One reason for this unpredictable behaviour is that potential difference between the anode and cathode is only one factor affecting the current density that flows between them. As current flows, various chemical changes will occur, shown schematically in Figure 7. Once the anode starts corroding, metal ions will go into solution. At the cathode, the usual cathodic reduction of water and oxygen will produce hydroxyl ions. These reaction products, along with sodium, chloride and other constituents of the electrolyte, can react with each other or the metal surface causing localised or widespread changes to conditions on the metal surface and within the electrolyte. As a result, the potential can change, resulting perhaps in new reaction products and conditions, resulting in further changes to conditions. The behaviour of a metal alone in a given environment will not be the same as the environment when that metal is joined to a different metal and corrosion reactions take place.

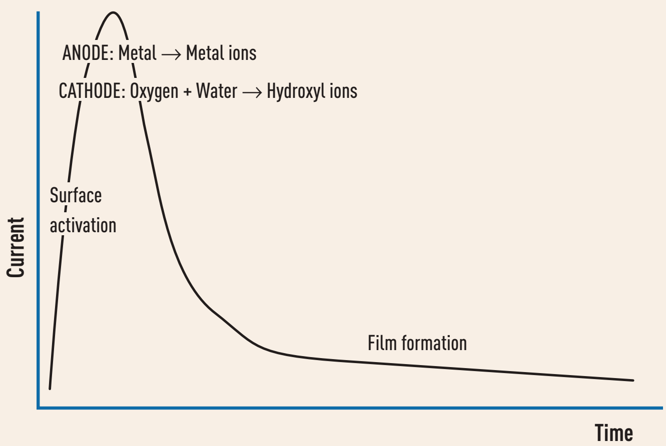

Figure 7: Ideal current variation with time when dissimilar metals are joined in aerated water.

4. Effect of Alloy Elements

Alloying elements can change the galvanic potential of a metal. Figure 8 gives the potential of some copper alloys from Figure 4 which shows that generally, more active alloying elements such as zinc will make the potential more negative, while more noble elements such as nickel make potential more positive. Figure 9 shows the sudden positive increase in potential when a steel alloy crosses the 12% chromium threshold to become a 'stainless steel'. There is no structural or phase change in the alloy; it remains in the alpha-phase (ferrite). The electrochemical change is because of the formation of the passive chromium oxide on the surface of the metal, not the change in bulk properties of the alloy.

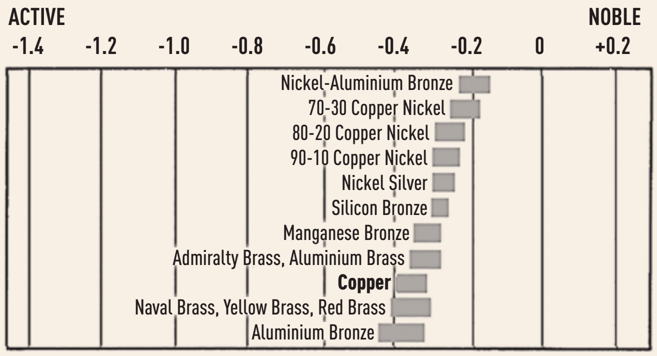

Figure 8: Electrode Potential of copper alloys.

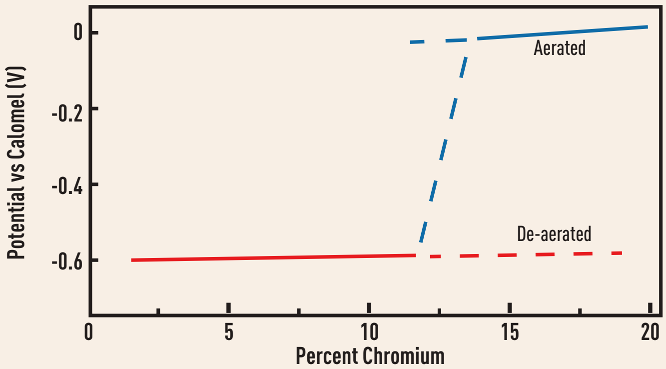

Figure 9: Potential of iron-chromium alloys.

Ennoblement of potentials can also be caused by other surface effects. A biofilm, such as will form in natural sea water, increases the rate of the oxygen reduction reaction on a passive metal such as stainless steel. Therefore, when connected to a more active metal such as copper or zinc (5), the current density due to galvanic coupling of the stainless steel will be greater than when connected to the same metal without a biofilm, such as would occur in laboratory artificial seawater or chlorine-treated sea water.

5. Effect of an Oxide Film

Unlike the Electrochemical Series, the Galvanic Series shows the galvanic performance of passive alloys – those with oxide or other films that provide enhanced corrosion protection. An indication of the protection provided by a passive film can be obtained by comparing the potential of the metal in the Galvanic Series with its potential given in the Electrochemical Series. If the metal shows significant ennoblement over its potential in the Electrochemical Series, then it means a passive film has formed in the environment in which the Galvanic Series was developed. The amount of ennoblement, that is how much more positive the potential is, will give an indication of the protection provided by the passive film. Table 1 shows potential of a number of metals from the Galvanic Series as well as Electrochemical Series potentials (converted to the

Saturated Calomel Electrode) and the difference between the two figures. Also included are stainless steels and nickel/chromium alloys, where the passive film is assumed to be provided by the chromium.

	Galv series vs SCE	EMF series vs SHE	EMF series vs SCE	Difference
Magnesium	-1.62	-2.37	-2.61	1.00
Zinc	-1.01	-0.76	-1.00	0.00
Beryllium	-0.96	-1.97	-2.21	1.26
Aluminium	-0.90	-1.66	-1.90	1.01
Cadmium	-0.69	-0.40	-0.64	-0.05
Mild steel	-0.66	-0.44	-0.68	0.03
Tin	-0.32	-0.14	-0.38	0.06
Copper	-0.34	0.34	0.10	-0.43
Chromium	-0.31	-0.74	-0.98	0.67
410 (13Cr) Stainless steel*	-0.31	-0.74	-0.98	0.68
430 Stainless steel*	-0.24	-0.74	-0.98	0.74
Lead	-0.22	-0.13	-0.37	0.15
Molybdenum	-0.27	-0.20	-0.44	0.17
Inconel 600 (78Ni-13Cr-6Fe)*	-0.16	-0.74	-0.98	0.83
Nickel 200	-0.15	-0.26	-0.50	0.35
Silver	-0.12	0.80	0.56	-0.68
304 (18-8) Stainless steel*	-0.08	-0.74	-0.98	0.91
316 (18-8-3) Stainless steel*	-0.05	-0.74	-0.98	0.93
Alloy 20 Stainless steel*	-0.01	-0.74	-0.98	0.98
Incoloy 825*	0.01	-0.74	-0.98	0.99
Titanium	0.01	-1.63	-1.87	1.88
Platinum	0.22	1.12	0.88	-0.66
*Assume chromium oxide passive film				

Table 1: Potential of metals in the Galvanic Series compared to EMF series.

Table 1 shows that titanium is much more noble than its potential developed for the EMF series, indicating it possesses very strong passivity. Stainless steels are also much more passive than the position of chromium would suggest. Both these observations are consistent with the performance of these alloys. Aluminium, beryllium and magnesium are also more passive than the EMF series would suggest, but this film is insufficient to make the metals noble. Contrary to popular belief, nickel shows limited passivity compared to these metals. Negative differences means that the metals are more anodic than their position in the EMF series would suggest, but the explanation for this is not clear.

Do metals with oxide films cause significant corrosion when acting as cathodes? Figure 10, using results from AS 4036, shows the galvanic effect of passive alloys on other metals. Alloy 825 causes significant additional corrosion only when connected with metals at least 500 mV more active (aluminium and steel) but it, along with other passive metals, has little effect on less anodic metals. Type 316 stainless steel causes some galvanic corrosion on zinc and steel (although less effect on aluminium) but again little corrosion of less anodic alloys. The greater the potential difference, the greater the risk but it would appear that galvanic corrosion is minor with passive alloys if the potential difference is less than 500 mV, although there are few results.

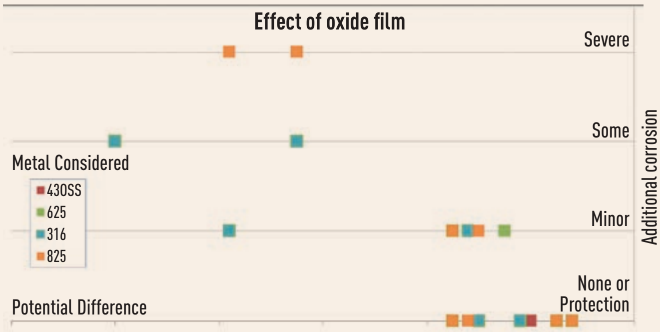

Figure 10: Practical galvanic performance with stainless steel cathodes.

6. Effect of Surface Area

Figure 11 shows the corrosion rate of the anodic material in sea water resulting from joining steel, copper and titanium of various area ratios to a coupled metal. A positive figure means the coupled metal acts as an anode; a negative figure means corrosion of the studied metal (steel, copper titanium) by contact with the coupled metal. (Uncoupled corrosion rates in mm/year are given with the coupled metal on the axis; the uncoupled corrosion rate of copper is 0.03 mm/year). The copper and steel results are from Reference (6) and the titanium from Reference (7), the latter with equal area linearly interpolated. There was no result for titanium coupled to zinc.

These results show that when the anodic area is much greater than the cathodic area (dark regions of the bars), there is little or no acceleration of corrosion when any metal, other than zinc, is connected to a more noble metal.

When the cathode is much larger than the anode (total length of the bars), copper alloys have a significant effect on zinc, aluminium and steel. Large areas of steel cause a similar acceleration of the corrosion of zinc and aluminium. Titanium causes additional corrosion to steel and copper alloys although it is a less effective cathode to aluminium. It has little effect on metals more noble than copper alloys, even when the area is large.

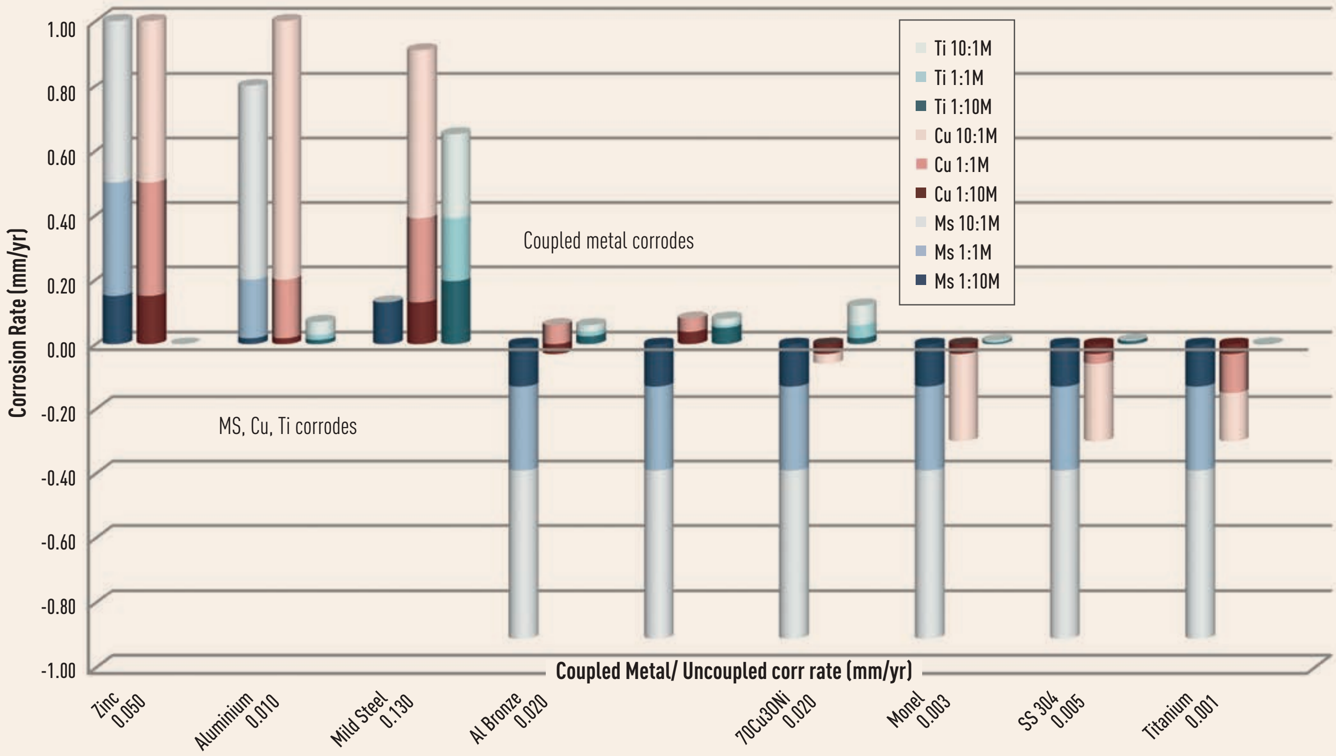

Figure 11: Corrosion rate of the anodic metal for mild steel, copper and titanium of different area ratios coupled to a second metal in seawater.

These results confirm that copper alloys cause little galvanic corrosion of other copper alloys, even with an unfavourable area ratio. However, Monel, stainless steel and titanium will have significant galvanic effect on copper when the cathode is large. The galvanic effect of all more noble metals on mild steel is significant (unless the steel area is favourable) and largely the same regardless of the difference in potential, confirming the early work of Bauer and Vogel mentioned above (2).

Trueman et al (8) measured the current flowing between galvanic couples of mild steel (MS), nickel aluminium bronze (NAB), Gunmetal (GM), Ferralium 255 (F255) and Inconel 625 (I625) of various area ratios in aerated seawater. Figure 12 summarises the results which show that:

- NAB is anodic to gunmetal (opposite of that predicted from the series potentials) although this is only significant with a small anode and large cathode.
- Other than this, mild steel is the only metal to suffer significant galvanic corrosion, although not if the area ratio is favourable. The galvanic effects between the metals of the other couples are minor, even with unfavourable area ratios.
- Copper alloys have a significant effect on mild steel, especially with a small anode and large cathode.
- Metals with passive oxide films (Ferralium 255 and Inconel 625) have little additional effect on corrosion of more active metals, except Ferralium 255 on mild steel with a small anode and large cathode.
- For all metals studied, a large anode with a small cathode is not a problem.

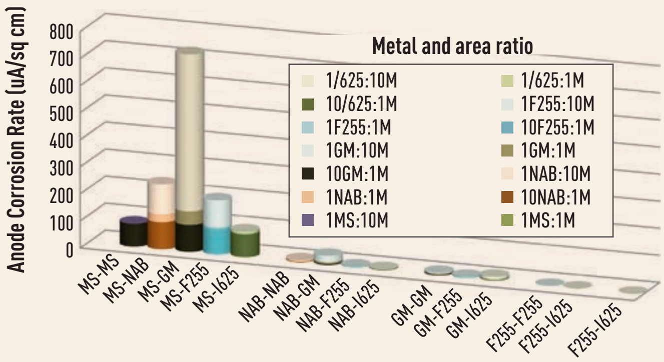

Figure 12: Effect of area ratio on galvanic corrosion of metal couples.

7. Effect of Environment

The environment is very important in determining galvanic behaviour. As well as influencing anodic and cathodic reactions, it will affect the formation and retention of a passive oxide film. For example, steel does not form a passive film in aerated seawater, but will in alkaline conditions. It would be expected to be more noble in such an environment. However, other environments such as acids are often very corrosive to many metals, and any galvanic acceleration is likely to of minor importance. In this section, we will briefly look at two environments, tap water and the atmosphere and compare behaviour to seawater in the examples already discussed.

7.1 Tap Water

Matsukawa et al (9), looked at the potential of a number of metals in flowing tap water and compared these potentials to those obtained in seawater. For most metals, the potentials became more noble by approximately 100 to 200 mV.

Lead was the exception as it produces a protective film in chloride environments. The potential of the aluminium did not stabilise in tap water, although the authors gave no explanation. The lower conductivity of fresh water would suggest that galvanic corrosion would be more confined to the point of contact between the two metals. Also, galvanic action should be less severe than in seawater with similar area ratios due to the formation of scale on the cathode and buffering of the pH by bicarbonate. Overall, similar relative behaviour between metal couples in fresh water would be expected.

7.2 Atmosphere

Galvanic corrosion in the atmosphere is of widespread importance, and generally galvanic behaviour in seawater is considered to be analogous to that in the atmosphere. However, this assumption is not necessarily correct. Galvanic action in atmospheres is even more difficult to study than in a fluid. Most importantly, the main method for laboratory studies of galvanic action, measuring potential and current, cannot be done in the atmosphere. Furthermore, galvanic action is largely concentrated at junction of the two metals. Corrosion products forming as the result of galvanic action can cause an open circuit or greatly increase resistance, altering behaviour. The great variation in corrosivity of different atmospheres further confuses the issue. If there is significant uncertainty with galvanic behaviour in seawater, then this magnified in the atmosphere.

Documents such as BS PD 6484 (10) and MIL-STD-889B (11) qualitatively give the level of atmospheric galvanic corrosion along with its effect in sea water for many galvanic couples. Comparing performance to that in seawater, such information shows that generally galvanic effects are less severe in an atmosphere, even a marine atmosphere. For example, MIL-STD-889B notes that stainless steels should not be connected to Monel, nickel and titanium in seawater, but the same couples are acceptable in marine or industrial atmospheres. Similarly, compatibility is observed between copper alloys joined to more cathodic metals in the atmosphere, but not in seawater.

Quantitative or even semi-quantitative data is much more difficult to find, mainly because of the problems noted above. The most successful technique appears to be the “wire-on-bolt” or CLIMAT method now widely used for atmospheric corrosion studies. Some of the earliest work was that of Compton and Mendizza in 1955 (12). The test involves the use of wires of the anodic material wound on a threaded rod of the cathodic material and exposed to the atmospheric environment under investigation. The net weight loss of the wire is determined after exposure to the environment for approximately 100 days. The wire has a relatively large surface area so large changes in weight percent will occur for small amounts of corrosion.

Figure 13 shows the net weight loss (subtracting the weight loss from free corrosion) for some “wire on bolt” couples boldly exposed at Point Reyes (a coastal site near San Francisco, USA) as an example of the work carried out. Some of the main findings are:

- As expected, magnesium shows the greatest corrosion, is anodic to all metals studied and shows significant weight loss. The type of cathode (other than zinc and aluminium which have less effect) does not a make a major difference.
- Zinc is corroded by the more noble metals studied except aluminium, which causes little galvanic corrosion.
- Aluminium suffers noticeable galvanic action when connected to iron, copper and brass with less effect from stainless steel and nickel alloys.
- Iron suffers some galvanic corrosion when connected to the more cathodic metals, but again the actual cathodic metal does not make much difference.
- Brass is not affected by steel, copper or Monel.

The anode area is less than the cathode area so the results should relate to actual performance of couples in the atmosphere, such as anodic fasteners in cathodic metals.

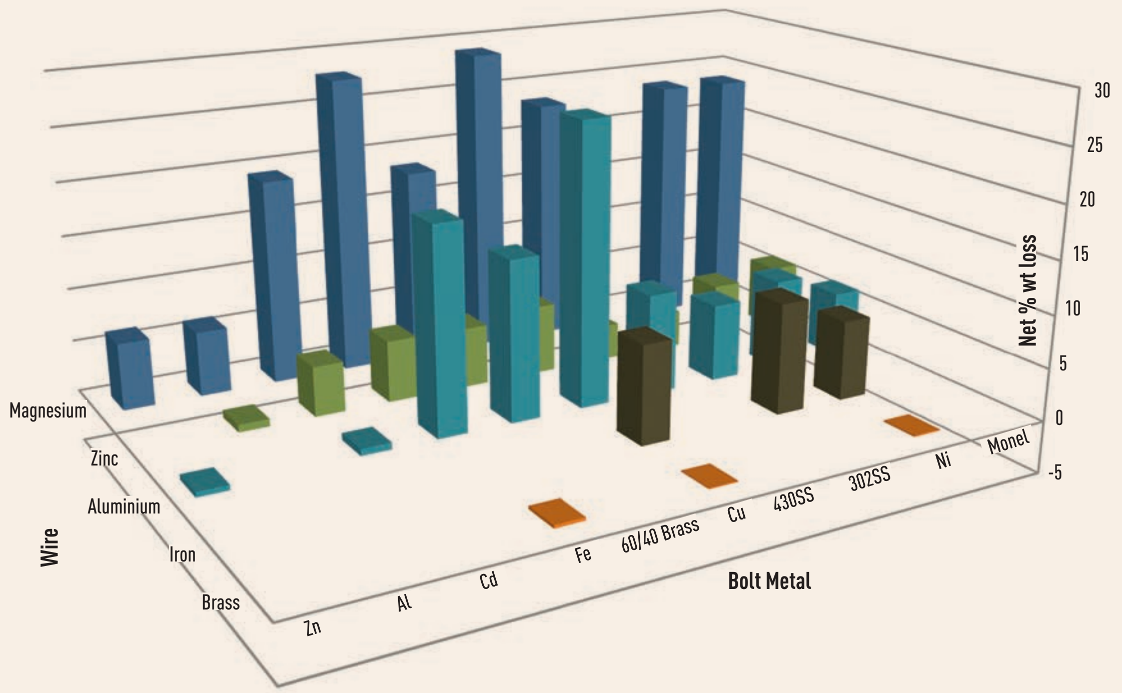

Figure 13: Percentage weight loss on “wire-on-bolt” couples exposed to a marine atmospheric environment.

An important issue with atmospheric galvanic corrosion is how far corrosion will extend into the anodic metal. Again, there is limited information available. The work of Zhang (13) summarised in Figure 14 shows the 'protection distance' provided by zinc to an adjacent steel surface for a range of environments. This gives an indication of how far galvanic action can extend from a junction. A (presumably clean) atmosphere at 100% relative humidity extended a fraction of a millimetre while an urban atmosphere is likely to extend only of the order of 1 mm, showing the limited electrolyte extent. Veleva and Cebada (14) found the 'galvanic corrosion zone' extended a somewhat greater distance, from 3 to 5 mm for Al/Fe, Zn/Cu, Zn/Fe and Fe/Cu couples exposed to a tropical rural and tropical marine atmospheric exposure. Shrier (15) notes galvanic corrosion in the atmosphere may occasionally extend up to 12 to 25 mm from the junction, but gives no evidence. Rain and dew drops of some millimetres in diameter covering the junction will allow the corrosion cell to operate over a distance depending on electrolyte conductivity and would appear galvanic effects in an atmosphere may extend up to about 5mm from a junction in more corrosive environments, but usually it is less than this.

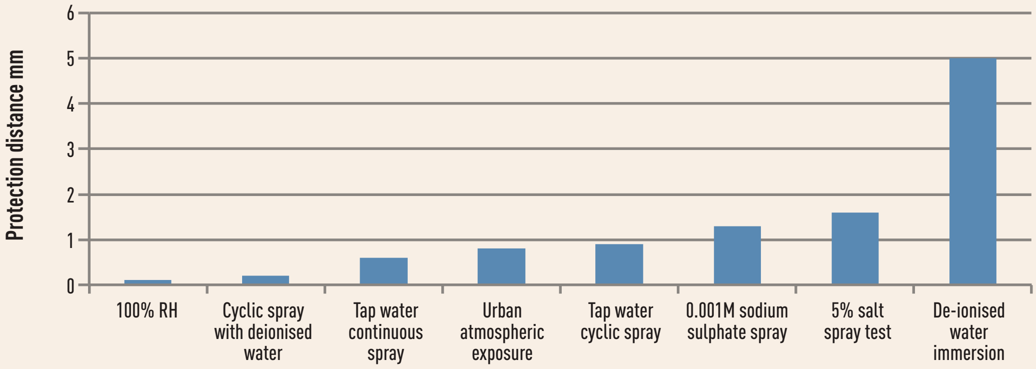

Figure 14: Protection distance on steel by zinc in various environments.

8. Conclusions

From the research work carried out over the past 200 years, the effects of galvanic corrosion can be roughly estimated using the Galvanic Series based on potential, but caution must be exercised. Table 2 gives a galvanic series in seawater with some comments based on some examples of this body of work discussed in this paper that may assist in practical estimation of the extent of galvanic corrosion. Some additional issues are:

- If the anode is much smaller than the cathode or the environment especially aggressive, or both, then galvanic effects are likely to be greater than noted.
- If the cathode is much smaller than the anode, or the environment more benign, then galvanic effects are likely to be less than noted and often can be ignored.
- A potential difference of about 0.4 volts or more between the two metals (0.5 volts if the cathode is passive) would normally be cause for concern. Potential differences less than this can be a problem with an effective cathode or unfavourable area ratio or both, with effects diminishing as the difference is decreased.
- Galvanic effects in the atmosphere are less than in sea water, although similar trends are apparent. Galvanic effects in the atmosphere are unlikely to extend much further than a few millimetres from the junction of the two metals.

Approximate potential in seawater (Volts vs SCE)	Metal/ alloy	Comments
Cathodic end		
+0.2	**Platinum, graphite**	Always effective cathodes
0	**Titanium, Ni/Cr/Mo and Ni/Cr alloys, super austenitic stainless steels**	Passive alloys act as less effective cathodes, except with strongly anodic metals
-0.1	**304 & 316 stainless steels**	Passive alloys, less effective cathodes
-0.1 to -0.2	**Nickel, Ni/Cu alloys, silver**	Effective cathodes for more anodic metals
-0.2 to -0.4	**Copper alloys**	Effective cathodes for more anodic metals
-0.3	**Ferritic, martensitic stainless steels**	Passive alloys, less effective cathodes
-0.4	**Lead, tin**	Effective cathodes for more anodic metals. Corroded by copper and nickel alloys, passive alloys have little effect
-0.6 to -0.7	**Cast iron, carbon steel, low alloy steel**	Corroded by more cathodic metals, protected by more anodic metals
-0.8 to -1.0	**Aluminium alloys**	Passive but corroded by more cathodic metals
-1.0	**Zinc**	Corroded by more cathodic metals
-1.6	**Magnesium**	Corroded by more cathodic metals
Anodic End		

Table 2: Practical Galvanic Series in seawater at ambient temperature.

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Quarterly Issue Deadlines for 2016

FEBRUARY	AUGUST
Booking Deadline 8 January	Booking Deadline 8 July
Material Deadline 15 January	Material Deadline 15 July
Publication Date 12 February	Publication Date 12 August
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Booking Deadline 8 April	Booking Deadline 23 September
Material Deadline 15 April	Material Deadline 30 September
Publication Date 13 May	Publication Date 28 October

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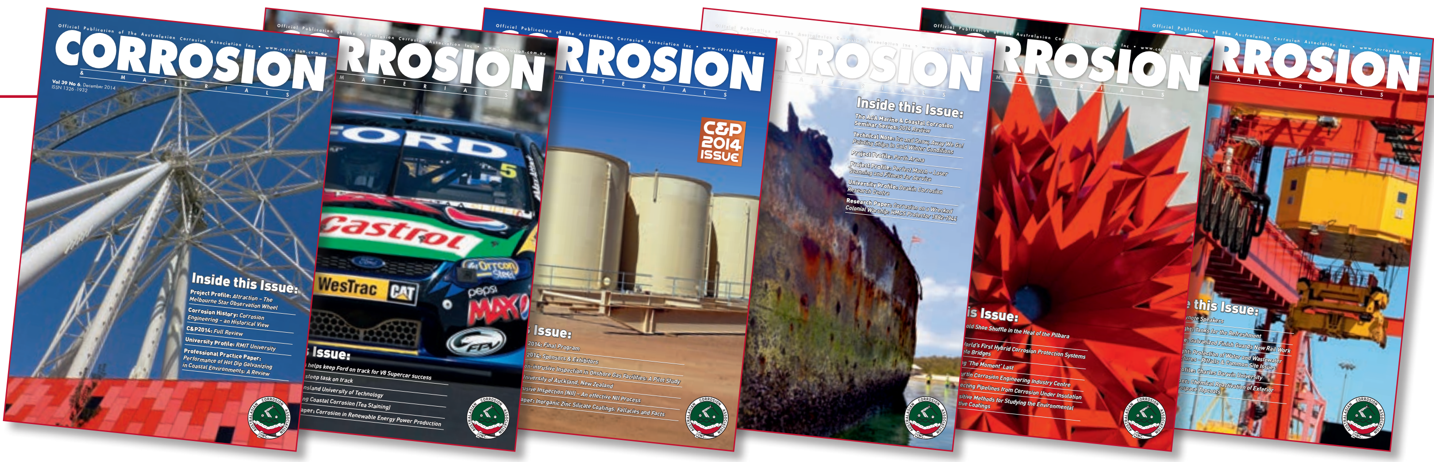

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