Paris 2024

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EUROPEAN CORROSION CONGRESS

**1-5 September 2024 Paris – France**

# Book of Abstracts
# - Short Talks -

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# Combination of Neutron and X-ray Computed Tomography for Artifacts in Bois de Châtel, Avenches, Switzerland

In this short lecture, we will present the early results of analyses done on archaeological artifacts buried in soil from the SNSF Sinergia Project CORINT, which aims at better understanding iron corrosion processes in various porous media using a new cutting-edge multimodal imaging technique. We will take a closer look at an archaeological nail, BdC 2, chosen as a case study among the other objects investigated. BdC 2 was excavated in Bois de Châtel, a forest archaeological site that is part of the Aventicum Roman Sites and Museum (SMRA) in the Avenches region, Switzerland. We performed neutron and X-ray computed tomographies (NCT and XCT) on this nail at the PSI facility, cold neutron beamline, ICON.

We will briefly share insights we have gained from the digitally reconstructed images of BdC 2 combining the neutron and X-ray tomographies. Emphasis will be put on features that would have been missed using conventional observations and analyses, showing the unique advantage of having NCT and XCT as an alternative analytical modality. For example, using reconstructed images, the nail's original surface (Limitos) can be determined in high confidence without performing any irreversible treatment and handling. Moreover, by performing digital segmentation, corrosion layers and features of the nail can be assessed in a truly non-intrusive way. This allows the same object to be re-imaged at various points in time to observe the evolution of its corrosion.

Thus, the overarching goal of this project is to utilize this multimodal approach to gain a new understanding of the impact of the soil conditions as well as the post-excavation procedures on the state of conservation of the archaeological objects. In the near future, thanks to predictive models currently being developed, it will be possible to estimate the general state of conservation of buried iron artifacts based on the site's characteristics. By getting access to the actual undisturbed corrosion state of iron archaeological artifacts, the status quo in archaeological site management, post-excavation handling of founds, and conservation and restoration procedures are now being challenged, thus, subsequently optimized.

# Protection of heritage copper metals from corrosion, using sol-gel-based treatments doped with carboxylic acids

***Letouzey Elysa [1,2], Neff Delphine[1] Maleval Marc[2], Mugherli Laurent[2]***

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To deal with the challenges of heritage conservation, previous studies have demonstrated the effectiveness of carboxylic acids as organic inhibitors on non-corroded metals, due to the precipitation of metal carboxylate, known as "metal soap"[1]. In the case of copper, interactions with the external environment lead to the formation of Corrosion Product Layers (CPL) on the metal surface: the cuprite ($Cu_2O$) at the inner part and then, the brochantite ($Cu_4(OH)_6SO_4$). CPL porous and hydrophilic nature complicates the use of hydrophobic corrosion inhibitors developed for the industry to preserve bare metals.

Therefore, this study proposes an innovative surface treatment assisted by a sol-gel process[2] that allows carboxylic acids to penetrate inside the CPL, while being non-toxic for users or environment and maintaining the integrity of the objects. Several formulations have been investigated by varying inhibitors (hepta-octa and decanoic acids), silicon-base (TEOS or TMOS) and solvents.

To improve the development of these treatments, a better understanding of inhibition corrosion mechanisms is required. Model samples of CPL made of synthetic brochantite pellets prior to the application of sol-gel coating to historical samples. A multi-scale analytical approach focuses on the porosity, the chemical composition and the crystalline structure of the sample in bulk and on cross section. This approach based on the complementary analyses by thermogravimetric analysis, Raman and SEM-EDS spectroscopy, BET and mercury porosimetry is presented in this paper. It shows as first results the silicon penetration resulting from sol-gel process and how the associated formulation of sol-gels affects the porosity, the depth of the treatment penetration and the velocity of the copper carboxylate formation.

(1) Donnici, M.; Baldo, M. A.; Daniele, S. An, *J. Mol. Liq.* **2021**
(2) Lob, S.; Neff, D.; Tran-Thi, T.-H.; Richter, M. C.; Rivron, C. , *Prog. Org. Coat.* **2024**

# Corrosion inhibition capability of chalcone-derived molecules

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Corrosion holds a significant impact at the industrial level, with a primary emphasis on metallic materials. Studies conducted in non-tropical countries indicate that economic losses due to corrosion range between 2% and 4.5% of the gross domestic product. For tropical countries, especially those with the geographical and climatological conditions of Costa Rica, even greater losses are expected [1]. Protection against corrosion of metallic structures in high relative humidity environments, regions with significant anthropogenic impact, and areas with continuous volcanic activity has generated interest in the development of novel organic corrosion inhibitors with less environmentally harmful impact, using synthetic routes that favor the concept of Green Chemistry [2].

In this work, the corrosion inhibition capability of seven chalcone-derived molecules (Figure 1) were carried out through electrochemical techniques (cyclic voltammetry, electrochemical impedance spectroscopy) in both organic and aqueous media in order to correlate electrochemical parameters (peak potential, reversibility) with molecular structure to derive information regarding the effect of specific functional groups on the performance of a molecule as a corrosion inhibitor. To assess their corrosion inhibition capacity, gravimetric tests based on ASTM G1-03 were conducted en acidic media [3].

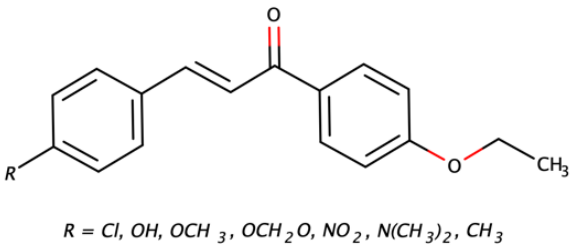


**Figure 1.** Molecular structure of chalcone-derived species.

## References

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[2] Sanni, O.; Fayomi, O. S. I.; Popoola, A. P. I. *J. Phys.: Conf. Ser.* **2019**, *1378*, 042047. https://doi.org/10.1088/1742-6596/1378/4/042047.

[3] Fernandes, C. M.; Alvarez, L. X.; dos Santos, N. E.; Maldonado Barrios, A. C.; Ponzio, E. A. *Corrosion Science* **2019**, *149*, 185–194. https://doi.org/10.1016/j.corsci.2019.01.019.

# Electrochemical and theoretical evaluation of thiocarbohydrazide as a brass (60/40) corrosion inhibitor in 3% NaCl solution and effect of temperature on this process

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## Abstract

This work presents an in-depth analysis of the inhibitory effects of thiocarbohydrazide (TCH) on the corrosion behavior of brass (60Cu-40Zn) in 3% NaCl solution similar to seawater using electrochemical measurements (electrochemical impedance spectroscopy and potentiodynamic polarization), scanning electron microscopy (SEM) and quantum chemistry calculations (DFT, MC, MD). The study's intent is to evaluate the possibility of using this molecule as an inhibitor for brass. The experimental results indicate that TCH has a very good corrosion inhibiting property toward brass in 3% NaCl. The calculated inhibition efficiency was 92.81% for a maximum concentration studied, namely, 1 mM TCH. Acceptable correlations were obtained between the inhibition efficiency and the calculated quantum chemical parameters. Studies of the temperature effect confirmed that the adsorption of TCH to the surface of brass is consistent with the Langmuir adsorption isotherm in the temperature range used. In addition, we found that this compound is characterized by a chemisorption process. Thermodynamic variables and activation energy values were determined and interpreted. The density functional theory (DFT) calculations, electrostatic potential surface (EPS), Monte Carlo (MC) and radial distribution function (RDF) simulations were achieved to obtain more insights about the adsorption mechanism of TCH towards the 60Cu-40Zn brass alloy (BA) surfaces. Moreover, the standard free adsorption energies $\Delta G^0_{ads}$ obtained suggest strong adsorption of the inhibitor to the metal surface. The presence of TCH on active sites on the brass surface was confirmed experimentally by SEM analysis.

# Water reliably replaces solvents in temporary corrosion protection

***Achim Losch*, Jessica Buchholz**

*Fuchs Lubricants Germany GmbH, Mannheim/Germany*

The novel solvent-free ANTICORIT WMD range is a more sustainable alternative to solvent-based corrosion preventatives for thin film and high performance applications.

## Background

Replacing solvent-based products with waterborne systems is an important contribution to improving the sustainability of temporary corrosion protection. However, while conventional emulsions are good for a short to medium-term protection, their performance is far too low for long-term protection.

## The solution

The new ANTICORIT WMD range provides an unprecedented level of protection without the use of solvents while maintaining a thin film. Other key features are:

- Solvent-free, mainly based on renewable raw materials
- Thixotropic, fast-drying and non-sagging film
- Stain-free on copper, brass, zinc, or aluminium
- Ready-to-use emulsion that can be further diluted as required
- Compatible with processes where solvent-based products are commonly used today
- Can be removed with hot water, aqueous cleaners, or hydrocarbon solvents

conventional CP emulsion | solvent-diluted CP | ANTICORIT WMD 9200

*Fig1: cast metal parts, dip-coated with thin-film preventive, 10 cycles ISO 6270-2 AHT*

# Assessment of Glassflake Reinforced Vinyl ester coating performance using Electrochemical Impedance Spectroscopy

***Venkatesh Ramanujam*[1], *Jing Jin*[2]**

*1) Jotun AS, Dubai / United Arab Emirates*

*2) Jotun AS, Sandefjord / Norway*

Glassflake Reinforced Vinyl ester coating is one of the widely used internal protective coatings for storage tanks due to their proven chemical & mechanical resistance. It's often recommended for chemical storage tanks for a broad spectrum of chemicals like acids, alkalis, organic solvent, and fossil & biobased fuel, etc.

Recent trend in the oil & gas industry coatings specification demands coatings' chemical resistance at elevated temperature. Traditional immersion test like ISO 2812: 2018 often follows with visual and pull-off adhesion assessment. This doesn't give in-depth overview about coatings' durability, and liability to future compromise.

This work aims to describe how Electrochemical Impedance Spectroscopy (EIS) can be used to assess the performance of Vinyl ester coatings against various chemicals. We can thus set up guideline for coatings' resistance recommendation.

# Cobalt octoate free vinyl ester coating for biofuel industry

## - A free fatty acid / water mixture resistance evaluation

***Jing Jin*, Gard Reian**

*Jotun AS, Sandefjord / Norway*

Glass reinforced unsaturated vinyl ester coatings have been proven as reliable tank coatings for biofuels, showing superior resistance compared to epoxy coatings, when exposed to natural free fatty acids, and their mixtures with water. Its critical accelerator, diethyl hexanoic acid salt with cobalt (cobalt octoate), is recently reported as toxic to reproduction, leading to a harsher HSE pictogram for products since 2024. In this work, we demonstrated that cobalt neodecanoate can work as the replacement to cobalt octoate and offer the same good free fatty acid resistance to the vinyl ester coating. The critical immersion performance of the candidates was evaluated after exposure to various fatty acids mixed with water, at elevated temperatures for up to 6 months. The results show excellent performance and it is therefore suggested that cobalt neodecanoate can be utilized as a more HSE friendly accelerator for unsaturated vinyl ester coatings.

# Evaluating Environmentally Assisted Cracking in Atmospheric Tests

***Dan Christy, Victoria Avance, Nate Brown, and Fritz Friedersdorf***

*Luna Labs USA, Charlottesville, Virginia, USA*

Environmentally assisted cracking (EAC) of high strength aluminium alloys in corrosive atmospheres presents significant maintenance and safety issues for aircraft and other lightweight structures. It is well known that the susceptibility of an alloy to EAC is dependent on the material, corrosive environment, and mechanical loading. For lightweight alloys, localized corrosion may progress into stress corrosion cracks and corrosion fatigue. The time dependent variations of environment and load may be significant factors in atmospheric corrosion and crack initiation and propagation. Other conditions that can influence these processes are the presence of galvanic couples and crevices that may increase the rate of corrosion degradation. Test systems and methods have been developed to better understand the interaction of these factors and evaluate material performance. These tests systems are design for both static and dynamic EAC measurements in atmospheric laboratory tests and outdoor exposures. Using the measurement capabilities, the influence of environment, alloy, alloy texture, and protection systems are being investigated. Intermediate RH and galvanic couples have been shown to increase EAC susceptibility, and non-chromate coatings are less protective compared to chromate containing primers. In this short lecture, the test systems will be briefly introduced, and the results of recent static EAC and corrosion fatigue tests will be presented.

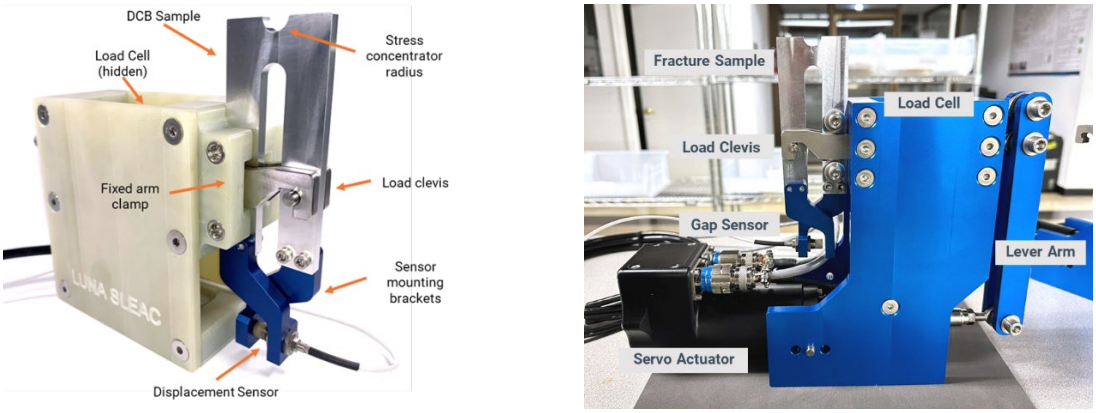


Figure - Static (left) and dynamic (right) mechanical test systems for EAC testing in laboratory and outdoor atmospheric corrosion tests.

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***Author[1], Author[2], Author[3] (underline the presenting author)***

*1) Organization, City/Country*

*2) Organization, City/Country*

*3) Organization, City/Country*

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# Investigation of the Effect of Mg on Morphology and Corrosion Performance of Hot Dip Galvanized Steel

*Refiye Ardalı, Celal Seyalıoglu*

*Borçelik Çelik Sanayii Ticaret A.Ş., Bursa/Turkey*

**Abstract**

For many years, galvanized coatings have been used in many industrial sectors as an economical and effective way to protect steel from corrosion. Developing and changing industry needs have shown that new coated products should be developed. Nowadays, Zn-Mg-Al coatings are attracting attention due to their better corrosion performance than conventional galvanized coating.

In this study, the effects of magnesium and aluminum added into the galvanizing crucible on the corrosion performance and coating morphology were investigated. The studies were carried out in the developed continuous galvanized coating prototype at 450°C molten bath. Coating morphology was visualized from the surface and cross-section by using SEM. To determine the corrosion performance, salt spray tests were carried out from both the surface and cut edge in comparison with the conventional galvanized coating.

**Results**

When the results obtained are examined, it has been observed that there are eutectic structures with high Mg content in the coating cross-section, which are different from conventional galvanize coating (Figure 1). The samples coated with Zn-Mg-Al showed approximately 6 times more corrosion performance in surface tests than the conventional galvanized coating of the same coating thickness as shown in Figure 2. This value increased up to 8 times in the cut edge tests as shown in Figure 3.

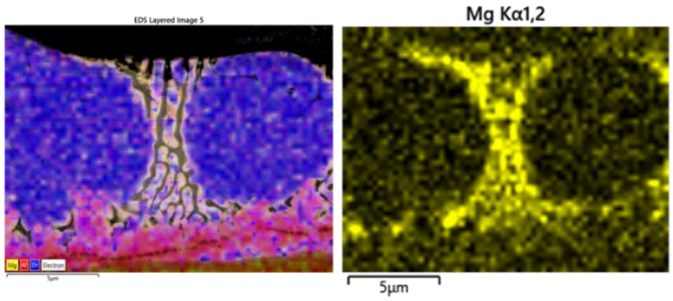



Figure 1

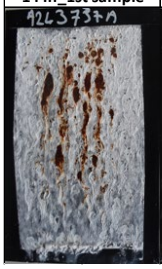
| Conventional galvanize coating | | Zn-Mg-Al coating | |
|---|---|---|---|
| 142g/m² | 146g/m² | 144g/m² | 144g/m² |
| 144h_1st sample | 120h_1st sample | 984h_1st sample | 1152h_2nd sample |
|  |  |  |  |

Figure 2 Salt spray results of surface

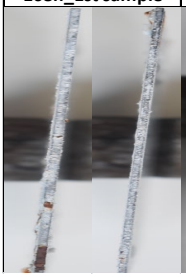
| Conventional galvanize coating | | Zn-Mg-Al coating |
|---|---|---|
| 142g/m² | 146g/m² | 144g/m² |
| 168h_1st sample | 140h_1st sample | 1344h_1st sample |
|  |  |  |

Figure 3 Salt spray results of cut edge

# *Preliminary corrosion behavior of zinc aluminum magnesium coating and pure zinc coating in typical soil environments*

***SHANG Ting, JIANG Guang-rui, LIU Quan-Li***

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**Abstract:** The SEM, GDS, and XRD are used in this article to study the structure of zinc aluminum magnesium alloy (ZMA) coating material and pure zinc (GI) coating material. A comparative study is conducted on the corrosion rate and mechanism of GI coating and ZMA coating at two soil test stations in Korla Xinjiang and Dagang Tianjin. The results showed that after 1 year, the corrosion rate of Korla GI was 2.59 times that of ZMA, Dagang GI was 1.5 times that of ZMA. For GI and ZMA coatings, the corrosion rates are both in the order of Dagang>Korla. The corrosion rate of zinc and zinc alloys in soil is mainly influenced by conductivity, pH value, salt content, microorganisms, etc. The higher the soil conductivity, the stronger the corrosiveness, while the lower the pH value, the stronger the corrosiveness. The order of conductivity values for the two sites is: Korla<Dagang, and the order of pH values is: Dagang ≥ Korla. These factors also affect the corrosion rate of materials by affecting the composition of corrosion products. The different rust layer structures of corrosion products have different inhibitory effects on cathodic oxygen reduction. In alkaline environments, the corrosion products of GI coatings are easily transformed into loose and conductive ZnO. Due to the anodic dissolution of $MgZn_2$ in the coating, $Mg^{2+}$can react with $OH^-$ to form magnesium hydroxide ($Mg(OH)_2$) on the surface of ZMA. Replacing zinc oxide with $Mg(OH)_2$ is believed to reduce the cathodic oxygen reduction reaction (ORR), and the increase in pH value at the cathode position is buffered, the alkaline zinc carbonate is stabilized , and the corrosion resistance is significantly improved. Therefore, ZMA coating material has broad application prospects in alkaline soil environments.

# Anti-corrosion property of ceramic epoxy coating with ionic liquid for seawater pipelines

***Mark Joseph Mitra Pasciolco[1], Qiong Wu[1], Wei Han[2], King Lun Yeung[1,2]***

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2) *Division of Environment and Sustainability, The Hong Kong University of Science and Technology, Clearwater Bay, Sai Kung, Hong Kong*

Corrosion has been the major cause of pipe failure in different countries around the world. One of the most cost-effective ways to prevent it is to apply coating to the internal lining of pipes, but industrial coatings available in the market still have an opportunity to improve their anti-corrosion property for long term use. This study aims to determine the feasibility of incorporation of ionic liquids (IL) to ceramic epoxy coating to enhance its anti-corrosion property. 1-butyl-3-methylimidazolium iodide (BMIM-I) was used as a candidate ionic liquid for this study. Tafel test have shown that the effect on the corrosion inhibition efficiency of addition of BMIM-I is little to none, with only 12.6 and 9.9% improvement to the coating with 25 and 100 mg/mL IL concentration, respectively. The % water uptake was also calculated using the results of the Electrochemical Impedance Spectroscopy (EIS) and the addition of IL was found to have helped moisture to enter the epoxy matrix, rather avoiding it to percolate through the coating. Thus, this type of ionic liquid may not be effective in inhibiting corrosion to occur and improvements on how it is incorporated to the epoxy matrix can be made.

# Advancements and Characteristics of Ultra-High Corrosion-Resistant ZnMgAl Alloy Galvanized Steel Sheets

***Seulgi So*[1], Sungjoo Kim[1], Taechul Kim[2], Myungsoo Kim[2], Doojin Paik[2]**

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*2) Automotive Steel Surface Research Group, POSCO Technical Research Laboratories, Gwangyang, Korea*

The Zn-Mg-Al alloy hot-dip galvanized steel sheet is known for its exceptional corrosion resistance compared to traditional Zn coatings of similar thickness. Despite being widely used across diverse fields, these steel sheets typically contain up to 3wt% magnesium. Due to the growing demand for enhanced corrosion resistance in harsh environments, a study was conducted to explore variations in magnesium and aluminium compositions to advance the development of a new generation of alloy-coated steel with ultra-high corrosion resistance. As a result, new alloy-coated steel with ultra-high corrosion resistance was developed. The Zn-5wt%Mg-Al coated steel was evaluated for its corrosion resistance and various properties. A direct correlation was observed between increased magnesium content and reduced corrosion loss. Notably, the corrosion resistance of the Zn-5wt%Mg-Al coated steel sheet surpassed that of conventional Zn-3wt%Mg-Al coatings by approximately 1.5 to 2 times. In summary, this study emphasizes the potential of this ultra-high corrosion-resistant coated steel sheet as a robust, sustainable solution. It not only helps conserve zinc resources but also contributes to advancing comprehensive life-cycle assessments.

# Accelerated environmentally-assisted crack initiation testing of additively manufactured 316L stainless steel in LWR environments: Preliminary results of an international Round-Robin initiative

***S. Ritter*[1], K. Sipilä[2], S. Dépinoy[3], J. Duff[4], C. Duhamel[3], M.A. Fuadi[4], Z. Fulin[5], M. Grimm[6], C. Guerre[7], M. Novák[8], R. Novotný[8], Z. Que[2], M. Rousseau[7], F. Scenini[4], A. Toivonen[2], Y. Vidalenc[9], B. Zajec[10], M. Zimina[5]**

*1) PSI, Villigen/Switzerland; 2) VTT, Espoo/Finland; 3) Mines Paris – Université PSL, Paris/France; 4) University of Manchester, Dep. of Materials & Henry Royce Inst., Manchester/UK; 5) Research Centre Řež, Husinec-Řež/Czech Republic; 6) Framatome GmbH, Erlangen/Germany; 7) Université Paris-Saclay, CEA, Gif-sur-Yvette/France; 8) EC – JRC, Petten/The Netherlands; 9) Framatome SAS, Le Creusot/France; 10) ZAG, Ljubljana/Slovenia*

Laser powder bed fusion (LPBF) is currently considered as a promising additive manufacturing (AM) method for replacing various nuclear power plant components. Characteristics of LPBF components may differ from conventionally manufactured components and their long-term performance in light water reactor (LWR) conditions and susceptibility to environmentally-assisted cracking (EAC) remains to be assessed.

A comprehensive in-kind Round-Robin screening test series (comprising of 18 long-term tests totalling more than 15 000 h) has been performed by ten European laboratories to assess the feasibility of an accelerated EAC initiation test method with LPBF 316L stainless steel in pressurised and boiling water reactor environments. Flat tapered tensile specimens, prepared by LPBF, were solution annealed or stress relieved. Their surface was either ground down to P2000 SiC paper or polished with oxide polishing suspension (OPS). An average strain rate along the gauge length down to $10^{-8}$ $s^{-1}$ was applied until the overall plastic deformation reached approx. 4 to 5 %. The specimen surfaces were inspected for cracks and critical stresses for EAC initiation were calculated based on the location of the last crack in the tapered section.

A preliminary assessment for EAC revealed that the LPBF 316L showed a relatively low susceptibility to EAC in both environments, but nevertheless EAC was observed in most cases. Although still more research is needed, this Round-Robin exercise has indicated the feasibility of the proposed testing approach and the gained results [1] will set a basis for future assessments.

[1] Ritter, S.; Toivonen, A.; Depinoy, S.; Zajec, B.; Duff, J.; Sipilä, K. (2023): POEAM Round-Robin environmentally-assisted crack initiation data for constant extension rate tensile tests in LWR environments on additively manufactured 316L stainless steel, version 1.0, European Commission JRC, [Catalog], https://doi.org/10.5290/71.

# Stress corrosion cracking of nickel-base alloy in the primary water environment of pressurized water reactors

***X K Liu*, Z F Yan, J Zhen, J Fan, H F Dou，D Z Qian***

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It is well know that the grid spring utilized as a fuel rod in reactors is fabricated from Inconel nickel-based alloy, which possesses exceptional strength, remarkable toughness, and excellent corrosion resistance. It serves as a crucial component within the fuel assembly of commercial pressurized water reactors (PWR). However, irradiation-induced stress corrosion (IASCC) has emerged as the primary failure mode for this particular element. For instance, incidents of IASCC-induced damage to Inconel 718 grid springs have been observed in a few commercial nuclear power plants in recent years. This damage often leads to fractures of at the end of the grid spring, and making the spring fragments stuck in the interior of the lower grid, in this case the fuel rod cladding may even be failure due to vibration wear. Therefore, it is very important and necessary to carry out IASCC research on this kind of nickel-based alloy.

In this study, an aged heat-treated nickel-based alloy was selected for analysis regarding its microstructure and phase composition. a stress-loading device was designed and manufactured, the unirradiated samples were subjected to stress corrosion experiment in a high-temperature and high-pressure water environment. The surface morphology, corrosion products, and crack initiation position of samples were analyzed. The preliminary results indicate that the predominant corrosion products of above samples are primarily composed of NiO and $NiFe_2O_4$. The corrosion samples will exhibit preferential corrosion at the locations of NbC and Ti (C,N) under experimental conditions, while stress-induced cracks are more likely to occur at these preferentially corroded positions. Subsequently, an irradiation capsule for irradiation experiments in the reactor is designed, and the irradiation experiment of the nickel-based alloy in the reactor will be carried out, then The stress corrosion experiment of irradiated samples will be conducted to compare and analyze the stress corrosion behavior of nickel-based alloy samples before and after irradiation.

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**WP04: 01_Work part sessions_03,  Nuclear Corrosion**

# Corrosion rate of encapsulated aluminium in mortar

***Aiala Urbegain[1], Virginia Madina[1], Nora Guenaga[1], José Luis Leganés[2]***

*1) Tecnalia Research & Innovation, San-Sebastian/Spain*
*2) ENRESA (Empresa Nacional de Residuos), Madrid/Spain*

**Objective:**

A widely used solution for the disposal of low and intermediate level radioactive solid waste is the immobilization in Ordinary Portland cement (OPC) based systems. These wastes may contain traces of metals in their composition, including aluminium.

Corrosion of encapsulated aluminium in the strongly alkaline OPC results in significant amounts of corrosion products and hydrogen gas, due to the presence of free alkaline water. This work evaluates whether the magnesium phosphate cement (MPC), could be an alternative to OPC based systems, because MPCs have a much lower pH. With this aim, gravimetric and electrochemical corrosion tests were carried out with aluminium embedded in these two types of cements.

**Results:**

Very little corrosion rates were measured for aluminium embedded in the MPC during the five months test period. Corrosion rates in the MPC were up to 50 times lower than those measured in OPC. Significantly, the highest corrosion rates in both types of cements occur during the first 24 hours.

**Conclusions:**

MPC materials are therefore potential candidates for the storage of low and intermediate level solid radioactive waste.

# On the Stress Corrosion Cracking of High Strength Austenitic Stainless Steels in Alkaline Brines at Elevated Temperature

Helmuth Sarmiento Klapper, Julia Ditmann, Sebastian Jesse

Baker Hughes, Baker-Hughes-Strasse 1, Celle, 29221 Germany

High strength austenitic stainless steels are the most used structural materials in directional and logging-while drilling technology. These materials have been designed to meet challenging requirements in terms of high strength in combination with high ductility and toughness, necessary for drilling applications. With the continued increase in operations with demanding service conditions, mainly characterized by high temperatures and corrosive alkaline halide containing environments, these materials have been pushed to their limits becoming prone to pitting corrosion as well as to environmental assisted cracking (EAC) including stress corrosion cracking (SCC).

Preliminary studies on pitting and SCC of these materials [1-3] have provided great insights into the mechanisms associated to pit and crack initiation in these materials. However, the question related to the transition from pitting into SCC remains open. In this study, specimens of different austenitic stainless steels in strain-hardened condition were exposed to alkaline brines at elevated temperatures commonly seen in drilling operations. In some cases, the electrochemical behavior of the materials was assessed, in some other loading conditions were also considered to induce crack initiation and propagation.

This paper discusses the observed correlation between pit propagation and SCC susceptibility observed on high strength austenitic stainless steels in alkaline brines at elevated temperatures.

[1] Klapper H.S., Stevens J., Wiese G., Pitting Corrosion Resistance of CrMn Austenitic Stainless Steel in Simulated Drilling Conditions – Role of pH, Temperature and Chloride Concentration, Corrosion, 69, p. 1095, 2013.

[2] Klapper, H. S., Zajec, B., Heyn, A., & Legat, A., Elucidating nucleation stages of transgranular stress corrosion cracking in austenitic stainless steel by in situ electrochemical and optical methods, Journal of The Electrochemical Society, 166(11), C3326-C3335, 2019.

[3] Klapper, H. S., Menendez C., Jesse, S., Pitting Corrosion Resistance Influencing Corrosion Fatigue Behavior of an Austenitic Stainless Steel in Chloride-Containing Environments, Corrosion, 76, p. 398, 2020.

# Comparison of phosphate and zirconium conversion coatings for corrosion protection of cross wire welds using a visual method for corrosion spread dynamics assessment

***Anna Poropat*[1], *Ivan Stojanović*[2]**

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In an effort to improve the material protection of steel products against corrosion, this study investigates the efficiency of two different conversion coatings - phosphate and zirconium - applied to steel samples with the same surface characteristics. This research aims to determine how these coatings, combined with varying powder coating thicknesses, affect the material's resistance to corrosion in aggressive conditions, using an unstandardised visual evaluation method of salt spray test, which provides detailed insight into the rate of corrosion spread. The observed area is the resistance spot weld, a critical site for corrosion initiation on wire products in real life. Preliminary results indicate a potential solution for significantly improving protection, with special attention paid to the mechanisms of action of these coatings and their interaction with powder coatings of different thicknesses. The comparative analysis offers insight into corrosion durability of spot-welded steel wire products. This research is expected to contribute to the selection of the optimal technology for anti-corrosive protection of resistance welded steel wires, aiming to extend the corrosion durability of products. It also seeks to identify a surface anti-corrosion protection technology that will minimise environmental impact.

**Key words**

resistance welding, cross welds, conversion coatings, powder coatings

# Improving Atmospheric Corrosion Forecasts: A Methodology for Data Imputation Preceding Machine Learning

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**Abstract：** This study primarily aims to analyze the relationship between atmospheric corrosion and environmental factors, particularly rainfall, in Qingdao, China. By examining a year's worth of galvanic-type atmospheric corrosion monitoring data, the research reveals seasonal variation patterns in corrosion in relation to environmental factors, with a special focus on rainfall. A significant achievement of the study is the introduction of a new method for the imputation of rainfall data, which is crucial for enhancing the accuracy of corrosion prediction models. Employing this improved data in conjunction with a newly developed time series forecasting algorithm, the study achieves better accuracy in predicting atmospheric corrosion trends. Overall, this research provides a novel and effective approach to atmospheric corrosion prediction by supplementing rainfall data and integrating time series forecasting.

# The Effect of Combination of Zinc Alloy Coated Steel and Chemical Conversion Coating on Red Rust Resistance of Exposed Steel Substrate

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## Objective

In order to improve anti-corrosive property in the steel exposed parts of Zn-Al-Mg-Si coated steel sheets, we investigated the effect of applying a chemical conversion coating including corrosion inhibitor to the zinc alloy coating and its mechanism.

## Result

The effect of the combination of zinc alloy coating and chemical conversion coating was investigated in a pure water spray cyclic corrosion test. It was shown that red rust resistance in the exposed part of the steel substrate is further improved by applying phosphoric acid-containing chemical conversion coating. It was speculated that the increase in the sacrificial protection distance to the steel substrate by the coating component also contributed to the suppression of the corrosion of the steel substrate.

In addition, the role of corrosion products was investigated. When a chemical conversion coating was applied, Mg and Zn of the coating element, and P of the chemical conversion coating components were detected on the steel substrate further from the interface between the coating layer and the steel substrate. As compounds consisting of Mg, Zn, $PO_4$, OH, and $CO_3$ protected the steel substrate, the corrosion of the steel substrate was suppressed even when the sacrificial anticorrosive action was difficult to work.

## Conclusion

Combination of a chemical conversion coating and zinc alloy coating improved the red rust resistance corrosion in the steel exposed. It was speculated because of the increase in the sacrificial protection distance and protection effect by corrosion products.

# On the multifunctionality of phosphate coatings

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Phosphate coatings are traditional treatments that increase the corrosion resistance of metals with simple and low-cost processes [1]. Iron phosphates ($M_xFe(PO_4)$, M= Zn, Mn, Li, …) may be used in different roles depending on their physical form. As films, the primary function is anti-corrosion, whereas as powders, the risen functionality is in the case of $LiFePO_4$ (LFP), an active material for lithium-ion batteries (LIBs). Batteries based on LFP are the automotive industry's reference technology nowadays. LFP is the material of choice because it is a non-toxic, low-cost, safe, and highly reversible material for positive electrodes [2].

This research aims to combine both functionalities by developing a phosphate coating for energy applications. LFP layers were grown by electrochemical methods on $Fe^0$ substrate sheets that will serve as the current collector in the final battery. Thus, the active material and the current collector are integrated into a single structure, avoiding the common poor electrical contact at the interface.

The layers were synthesised by cyclic voltammetry in a three-electrode cell, with a scan rate of 15 mV/s between 10 and 40 cycles. The cycling limits were -0.75 to 1.4 V vs SCE. The electrolyte was 2.85 M $H_3PO_4$ + 2.85 M LiOH, so $Li^+$ was expected to be incorporated into the initial passivation phosphate layer formed on the iron sheet. This incorporation was verified following the evolution of the Flade potential with cycling.

To study the microstructural and chemical evolution, SEM/EDX and XRD techniques were employed, which revealed that the synthesised layer (cathode material) is highly porous and shows good adhesion to the current collector.

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# Corrosion inhibition of aluminum alloy by mechanochemically synthesized silicate-phosphate pigment

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In the presented work, a composite anti-corrosion pigment was obtained by mechanochemical interaction of natural silicate (wollastonite) with acidic zinc dihydrogen phosphate $Zn(H_2PO_4)_2$. The method of solid-phase synthesis in a high-energy planetary ball mill was used for this.

The morphology of the "wollastonite/zinc dihydrogen phosphate" pigment was investigated by SEM/EDX analysis and the presence of silicon, calcium, phosphorus, and zinc atoms in its composition was established. At the same time, XRD analysis did not detect crystalline zinc phosphate in the synthesized pigment, which may indicate the formation of a nanocrystalline amorphous phosphate phase on the surface of wollastonite.

Corrosion inhibition of aluminum alloy by composite pigment in synthetic acid rain was investigated using the EIS method. It was established that it significantly increases the charge transfer resistance $R_{ct}$ and decreases the conductivity $Y_0$ of the element of the stable phase $Q_{dl}$ of the aluminum alloy compared with a simple mixture of its original components. The increased anti-corrosion properties of the composite pigment can be caused by the mechanochemical interaction of its components with the formation of a phosphate shell on the inert silicate core, which is more effective than the zinc phosphate pigment. After exposure of the aluminum alloy in the composite pigment extract, a corrosion-resistant film was formed on its surface, probably consisting of zinc and calcium phosphates.

Thus, the obtained composite pigment has high protective properties, its characteristics are superior to commercial zinc phosphate, and it is promising for use in paint primers on aluminum alloys.

**Acknowledgment.** The work was carried out with the partial financial support of the Ingeborg-Gross-Stiftung (Hamburg, Germany).

Efforts at replacing environmentally benign and carcinogenic chromate in conversion coating on Al and its alloys are yielding some positive outcomes. Electrochemical assessments of ferric ions and hybrid coatings based on ferric ion/chromate as well as ferric ion/molybdate in 3.5% NaCl revealed the superiority of ferric coating over the hybrid coatings. Corrosion rate for ferric ions was 0.099mm/yr; while 0.246mm/yr was recorded for ferric ions/chromate, and rate for ferric ions/molybdate coating was 0.304mm/yr. From scanning electron microscopy, the coatings comprised of irregularly shaped materials which highlighted the grains and sub-grain boundaries of the substrates. However, cracked morphologies which are thought to be weaknesses prevailed in the hybrid coatings. EDS, within the limits of detection revealed that the elemental components of the coatings were Al and O for the ferric ions; Al, O and Cr for Ferric ions/chromate and for ferric ions/molybdate, Al, O and Mo respectively. There were no obvious disparities among the adhesion performances of the coatings. These pretreatments are suitable replacements for highly concentrated generic chromate conversion coatings..

# Designing of the high corrosion-resistant magnesium alloy based on the dissolution-ionization-diffusion-deposition (DIDD) model

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Abstract: A new designing idea was proposed for the high corrosion-resistance magnesium (HCR-Mg) alloy based on dissolution-ionization-diffusion-deposition (DIDD) model. HCR Mg alloy consists of low-alloying element (LA) and micro-alloying element (MA), characterized as “Mg-LA-MA” alloying system. The downwards-magnifying effect of MA-LA-Mg on the nucleation played a key role in achieving passivation behavior. The designed HCR Mg alloy (Mg-3Nd-1Gd-0.6In) showed superior corrosion resistance (near AA2024 alloy) and good mechanical performance (UTS, 259.30 ± 0.27 MPa). Overall, a universal way for designing new alloy systems with superior corrosion resistance was proposed, promising for future applications..

**Keywords**: the dissolution-ionization-diffusion-deposition (DIDD) model; Corrosion; Mg alloys.

# Quantifying Local Corrosion Rate in Atmospheric Storage Tanks Utilizing Advanced Numerical Simulations

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The familiarity we possess with traditional fuels stems from extensive research, rigorous testing, and decades of manufacturing and operational expertise. Presently, a wave of novel and alternative fuels, utilizing new feedstocks and manufacturing methodologies, is emerging in the market. However, owing to their recent introduction and the challenges in scaling up to mass production, certain alternative fuels may exhibit variability and pose concerns related to corrosion. Atmospheric storage tanks play a critical role in the safe and reliable handling of hazardous substances in major accident hazard establishments. To prevent potential leaks, it is essential to regularly monitor the thickness of their bottom sections. This typically involves comprehensive inspections that are conducted every 10 years or more. Despite the regular thickness assessments, discrete measurements cannot fully capture the most severe corrosion damage, particularly in localized forms like pitting.

The primary objective of this investigation is to meticulously trace, analyse the intricate evolution of the metal/electrolyte interface and model the underlying mechanisms governing the initiation and propagation of single as well as multiple interacting corrosion pits. In pursuit of this objective, the research employs the computational framework of COMSOL Multiphysics for conducting numerical simulations executed on a model that intricately amalgamates the complex dynamics of the electrolyte and the electrochemical characteristics at the interface, thereby formulating a phase-field dependent representation of the Nernst-Planck equations.

The conducted analyses afford the opportunity to discern and articulate the intricate functional interdependencies governing the corrosion rate concerning pivotal parameters. These parameters encompass not only the electrochemical potential but also encompass variables including the spatial distribution, the number, mutual distance among pits, alongside the influential role played by the electrolyte's chemical composition.

# Laboratory Technologies for Corrosion Inhibitor Residuals Analysis

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**Abstract**

CIs have been detected in water systems using multiple different physicochemical techniques which are mostly instrumental ones. These techniques, involving chromatography and spectroscopy, are quite sophisticated in the sense of detection limits and accuracy of the measurement. However, the major drawbacks include their limited portability, and rather expensive instrumentation, which hinder their deployment and use in the field. Chromatographic techniques require extensive sample preparation while spectroscopy is considered non-specific and non-responsive towards compounds that are non-absorbing in certain wavelength ranges. Mass spectrometry can be an alternative to those techniques but with it comes with a huge cost burden. Electrochemical sensors, on the other hand, are very inexpensive tools to continuously monitor redox species and furnish good selectivity for those species based on the selected oxidation-reduction potential. Moreover, the diversity in the selection and modification of electrode materials provides a quick adjustment, rather switching of the sensor functions against a certain analyte or a class of analytes.

**Key words:** corrosion inhibitors, chromatography, spectroscopy, wavelength, Electrochemical sensors, oxidation-reduction potential, residuals.

# Dissolution of Cr oxide film in $H_2SO_4$ solution monitoring by atomic emission spectroelectrochemistry (AESEC)

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The corrosion resistance of Cr containing alloys depends upon the presence of Cr oxide passive film. The electrical and electrochemical properties of this film are therefore paramount to the corrosion resistance of the alloy. A particular property of interest is the electrochemically induced dissolution of the film at (1) anodic potentials which characterizes the beginning of the transpassive domain; and (2) at cathodic potentials which is frequently used to remove the passive film. In anodic dissolution, a common estimation of the transpassivation behavior is the oxidation of an insoluble Cr (III) film to a soluble Cr (VI) species [1]. The mechanism at cathodic potentials however is unclear. The Cr (III) could reduce to Cr (II) and dissolve in the acidic solution based on thermal dynamic view [2], or physically removed by $H_2$ evolution.

In this work, we seek to determine relationship between Cr (III) dissolution potential and current in both the cathodic and anodic domain using AESEC to directly monitor Cr dissolution and electrical current simultaneously. The novelty of this work is to use model Cr (III) oxide films on a gold (inert) substrate such that the oxide film makes the only contribution to the total dissolution. In this way, we can isolate the electrochemistry of the passive film.

The dissolution process of chromium oxide films on inert metal substrates in sulfuric acid solution is complex. For the anodic dissolution reaction, by controlling the passivation potential to reduce the oxygen evolution reaction, the relationship between current and dissolution of Cr elements aligns with the theory of $Cr^{6+}$ dissolution; however, the cathodic dissolution process is much more intricate. In this presentation, I will discuss the cathodic and anodic dissolution processes of chromium oxide films in solutions of varying acidity, establish the interrelationship between current and dissolution amount, and clarify the mechanism of film dissolution.

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# Understanding Behaviour of Passive Film Formation and Breakdown of High Nickel Alloys During Electrochemical Meausurement

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Corrosion studies of high nickel content alloys play a critical role in ensuring the longevity and performance of materials in demanding industrial applications. This study will focus on recent advances made in the field of corrosion research, focusing on refined measurement techniques designed to obtain a better understanding of passive film formation and rupture during electrochemical measurements, as well as the role of nickel on passive film characteristic.

Traditional methods for corrosion analysis often fall short in capturing intricate details of the dynamic processes occurring at the alloy-electrolyte interface for corrosion resistant alloys with nickel content in the range of 35-50 wt%. This study discusses combination of measurement techniques that help overcome these limitations, opening up possibilities for improved and more precise corrosion studies.

The presentation will showcase improved engineering approaches, for instance potentiostatic polarization, electrochemical impedance spectroscopy, in-situ microscopy, and surface analytical techniques. These methods offer improved resolution and sensitivity, enabling to unravel the complexities of passive film evolution and rupture mechanisms in high nickel content alloys. The significance of these advancements lies in their potential to provide a deeper understanding of corrosion phenomena in developing more robust and corrosion-resistant alloys.

# Material Acceleration Platform (MAP) for corrosion research: A case study on optimization of corrosion inhibitor mixtures

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The discovery of novel corrosion protection materials by conventional approaches and manual experimentation is a slow and expensive process. At the same time, the literature is literally exploding with papers suggesting new and very often exotic compounds that promise a certain level of corrosion protection. In this project, we follow the contrary hypothesis that well known and widely available inhibitors when dosed in application and material tailored mixtures would provide adequate corrosion protection and will have better chances for commercialization. Thus, the aim of this project was to establish a platform that will enable autonomous exploration of the large parameter space of already existing corrosion inhibitors for synergistic effects based on descriptors generated from electrochemical characterization data.

We run campaigns for optimization of inhibitor mixtures for carbon steel and AA 2024 T3 aluminium alloy. In one campaign, six commercially available inhibitors (three organic and three inorganic) and their combinations were tested to find new cocktail chemistries. To maximize the throughput of the MAP, new property descriptors had to be defined and fast-but-reliable measurement routines had to be developed. We have tested cyclic voltammetry, potentiodynamic polarization with different scan rates and ranges as well as chronoamperometry to obtain a reproducible test sequence. The leads obtained from the platform were validated with the classical corrosion analytics toolset using electrochemical methods, spectroscopic and microscopic techniques.

One major output of this project is the MAP-dataset of great reproducibility, growing with each campaign we run. Our results support our hypothesis with an unexpected twist, namely that compounds that don’t show adequate or any corrosion inhibition effect when dosed alone, can lead to excellent corrosion inhibition when dosed in the right combination. The presentation will summarize the workflows of our MAP and the highlights of the results from different campaigns.

# Insights on the corrosion products precipitation in interfacial macro-pores: similarities between reinforced concrete and iron archeological artifacts in soil

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The corrosion mechanism of metals embedded in opaque porous materials is highly influenced by, among other factors, the porous network of the medium and the characteristics of the medium-metal interface, such as the local moisture conditions and the pH of the electrolyte at which corrosion occurs. Even though significant research has been conducted to elucidate the mechanisms of metallic corrosion in porous media (i.e., steel in concrete, archeological artefacts in soil, etc.), the opacity of the matrices and the complexity of the interfacial micro-scale processes involved when corrosion occurs and propagates often hinder the formulation of conceptual and analytical models that can tackle this problem from a fundamental perspective. In this context, studying certain inter-related mechanisms has been possible only recently through advanced experimental techniques, such as bimodal X-ray and neutron computed tomography (X/n CT). As a collaboration within the interdisciplinary CORINT project funded by the Swiss National Science Foundation (https://corrosion-corint.ch/), this study reports on the application of X/n CT and SEM analysis to investigate how corrosion products precipitate in macro-pores at the metal-media interface in the case of steel in concrete and of a Roman archaeological iron nail embedded in soil. Even though the interfacial conditions may be considerably different in the two systems (e.g., pH of the electrolyte, size range of the porous network, ageing, etc.), a very similar corrosion product precipitation pattern is visible. When favorable conditions for metallic dissolution in the proximity of an interfacial macro-pore are present, corrosion products precipitation occurs firstly as a dense layer along the edges of the void. Precipitation of consequent layers of corrosion products takes place growing inwards in the void volume. Microscopy analysis suggests that phase transformation of the different corrosion products compounds occurs over time and, most likely, depending on the local chemical conditions. These observations, as well as the implications that this growth pattern may have on corrosion propagation, will be comprehensively discussed.

# Improving pitting resistance of Mo-containing stainless steels via chloride-assisted stabilization of the passive film

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## Abstract

Molybdenum is well known as a beneficial alloying element which entitles stainless steels an enhanced resistance against chloride attack. It is generally accepted that Mo modifies passive film to be more resistant to chloride attack. Using aberration-corrected transmission electron microscope and a precise super X-ray energy-dispersive spectrometer analysis, we have examined the structural and compositional evolution of the passive films induced by the chloride ion introduction, and clarified the strong dependence of Mo accumulation in the passive films as well as the film thickening on the chloride incorporation into the films, which provides new experimental insights on the well-known role of alloying element Mo in enhancing the corrosion resistance. In combination with the computational modeling, it is proposed that Molybdenum takes advantage of the attacking of chloride ions to the passive films to achieve transport in the film and participation in the oxide growth. Based on this clarification, we conceive a strategy for improving the stability of the passive film, which involves fully utilizing the chloride ions to activate Mo and in the meanwhile exerting a slight aggressivity towards the passive film. By introducing a low concentration of chloride ions into the electrolyte in which the FeCr15Ni15Mo2 single crystal as well as the 316L stainless steel are anodically passivated, we have obtained the modified passive films where the alloying element Mo is accumulated at the outer later and the thickness is increased. The as-received modified passive films behave a greatly improved stability and make the metal more resistant to pitting corrosion. Our results show the broad prospects for useful practical applications in anti-corrosion interventions.

# Internal Corrosion Mitigation by using Non-Metallic Materials at Wash Water Line System

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**Abstract**

Permanent solution to the chronic *corrosio*n problems in plant of wash water system that led to increasing number of defects and to generate plants priority list that shows the most affected plants which should be given more attention. The study covered all wash water system piping in  excluding two plants (D-6 & H-2) since they don't have wash water system. The assessment covered the piping from Wasia water supply well, passing through the degassing vessel (D-215) serving the dehydrator, desalter and WOSEP equipment. Majority of the wash water corrosion failures occurred in the isolated part of the jetting lines. The contributed factors that exist in this part of wash water system leading to corrosion and defects are water stagnancy/No sloping and intermitted operations, salinity of Wasia water, poor coating application and Insufficient corrosion inhibition for batch and continuous treatment.

**Keywords:** *Ccorrosio*n, Wash Water, Jetting Lines, Wasia, Continuous Treatment, Batch

# Evolution and Prospects: Buried Pipeline Coating's Technologies from Past to Future

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## Abstract

This paper explores the historical evolution and future prospects of underground pipeline coating technologies in oil & gas company, focusing on their critical role in corrosion prevention. From the early use of coal tar enamel in 1940 to modern high Tg fusion bonded epoxy (FBE) and advanced nanocomposite coating, this study examines the progression of materials and techniques used to protect pipelines from corrosion. Additionally, the paper delves into the Saudi Arabia environmental and performance challenges faced by existing technologies and anticipates the direction of future advancement in this critical operation.

## Introduction

The transportation of hydrocarbons through underground coated pipelines is a cornerstone of oil & gas company. Ensuring the integrity and longevity of these pipelines is essential to prevent environmental disasters, maintain economic stability, and secure energy resources. One of the key challenges in pipeline maintenance is corrosion, which can lead to leaks, ruptures, and costly repairs. Therefore, pipeline aging is at risk of corrosion failure due to coating shielding cathodic protection, localized corrosion and stress corrosion cracking. To combat this issue, underground pipeline coatings have evolved significantly.

# Hydrogen solubility determination in spheroidal cast iron

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Nowadays, there is a growing interest in blending natural gas with green hydrogen as a possible solution to decrease the carbon fossil dependence and reduce the production of CO2. The hydrogen embrittlement (HE) resistance of carbon and alloyed steels was analysed and studies into this matter continue; however, the number of research studies on other metal alloys is limited.

Therefore, the Horizon Europe CANDHy Project investigates metal materials different from the traditional steels, with a methodology involving simultaneous test in independent R&D platforms with a common methodology. Cast irons are among the most widely used metal alloys in the distribution of low-pressure natural gas. The starting point to induce embrittlement phenomena is that the hydrogen can be dissolved within the metal material and be accumulated in irreversible traps or as diffusible hydrogen. The latter is considered the main responsible for the phenomena of embrittlement.

The few studies present in the literature on cast iron, attribute at ferrite/graphite interface a predominant role of hydrogen supply and diffusion. In this regard, the solubility of hydrogen within the cast as a function of the shape and distribution of the graphite was investigated. The results will be used in the analysis of the behaviour of new and vintage cast irons towards the HE determined within the CANDHy project.

# A Phase Field Approach to Simulating Hydrogen Embrittlement in Hydrogen-Blended Natural Gas Infrastructure

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Hydrogen is a key player in the transition to a low-carbon energy system in Europe, playing a crucial role in decarbonizing sectors like transport and industry. Hydrogen production is expected to increase significantly in the coming decades, reaching over 100 million tons by 2050. Repurposing existing natural gas pipelines for hydrogen transport offers a cost-effective solution, but a thorough evaluation of hydrogen's effects on pipeline integrity and safety is crucial to determine the feasibility and safety limits of hydrogen-natural gas blends. Hydrogen embrittlement, a significant issue in various industries, could hinder the utilization of hydrogen as a future energy source. To effectively address this challenge, we need a comprehensive understanding of how hydrogen weakens the ductility and fracture resistance of metals.

The phase field models are a promising tool for simulating HE-induced crack growth and understanding the relative importance of various model parameters is crucial for improving its accuracy and applicability.The goal of the present study is to a comprehensive analysis of the phase field model, which builds upon Griffith’s thermodynamics framework, systematically varying key parameters such as hydrogen concentration percentage.

The model builds upon a coupled mechanical and hydrogen diffusion response, driven by chemical potential gradients, and a hydrogen-dependent fracture energy degradation law grounded on first-principles calculations and displacements, phase field order parameters and hydrogen concentration are the primary variables.

This analysis provides valuable insights into the model's robustness and identifies areas for further refinement, paving the way for more reliable and accurate predictions of hydrogen-induced crack growth.

The findings from this research will be instrumental in enhancing the safety and reliability of hydrogen-blended natural gas distribution networks, actively supporting the energy sector's shift towards sustainability.

# The effect of hydrogen on soil corrosion of natural gas pipelines

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**Abstract**

Adding hydrogen to natural gas pipelines for transportation can reduce the cost of hydrogen transport and promote the rapid development of hydrogen energy. The effects of hydrogen on the soil corrosion of natural gas pipelines (20#, X52, and X65 steel) were investigated using electrochemical measurements, SEM, EDS, and XPS. After the addition of hydrogen, the risk of soil corrosion for natural gas pipelines increased. The corrosion mechanism of these pipelines changed, leading to alterations in the corrosion product film. With hydrogen charging, the quantity of spherical corrosion products increased, and porous corrosion products appeared. Simultaneously, by combining finite element simulation, a residual life assessment model for natural gas pipelines incorporating hydrogen was established, based on corrosion and mechanics.

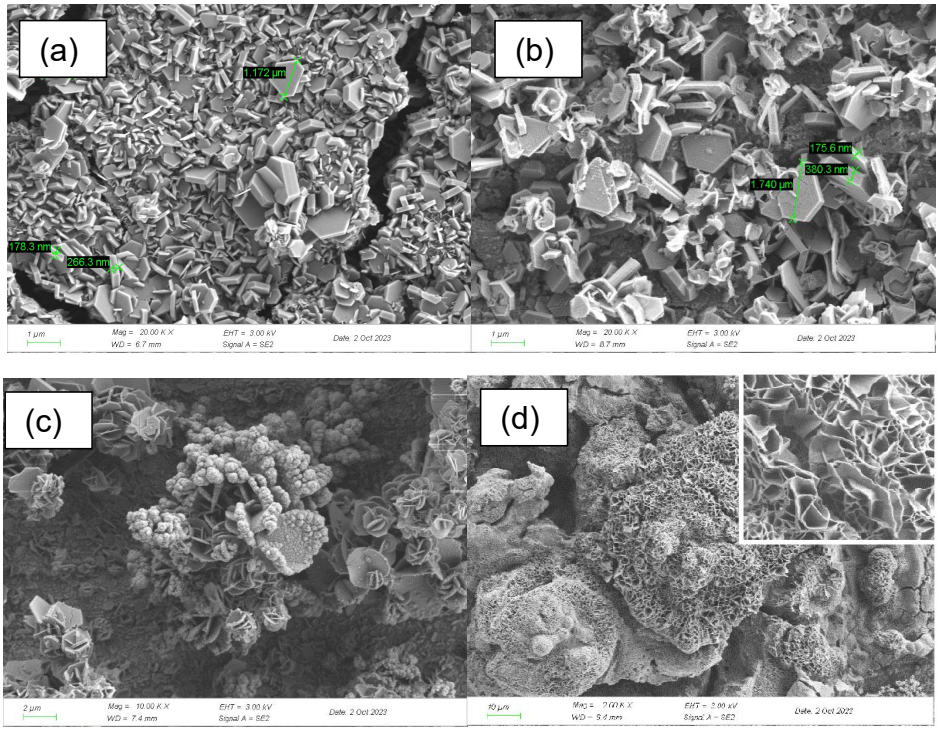


Image 1 - Morphology of corrosion product film of X65 (a) Hydrogen-free, (b~d) after hydrogen charging

# In situ investigation of the reduction of iron oxides as indirect hydrogen detection method in XPS

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Since the degrading effects of hydrogen on advanced high strength steels is a current topic in corrosion research, the challenging detection of hydrogen needs to be addressed. Most characterization methods are not able to detect hydrogen directly, necessitating alternative techniques. Our work wants to contribute to this challenge with a self-developed liquid cell for X-Ray photoelectron spectroscopy XPS, with which we assess the chemical state of oxidic iron and its reduction processes by hydrogen in situ. Hydrogen is introduced at the hydrogen entry side into a steel sheet through the interaction of perchloric acid with the zinc layer of galvanized dual-phase steel DP1000. On the opposite, hydrogen exit side, iron oxides are reduced by hydrogen which diffused through the steel. A shift of the main oxidic peak in the order of few eV towards lower binding energies as well as the position of the shake-up satellites are used to analyse the change of iron oxides (see Fig. 1). The quantity of iron transitioned from the third to the second oxidation state was estimated, allowing a discussion of the reduction processes based on a proposed oxide layer model.

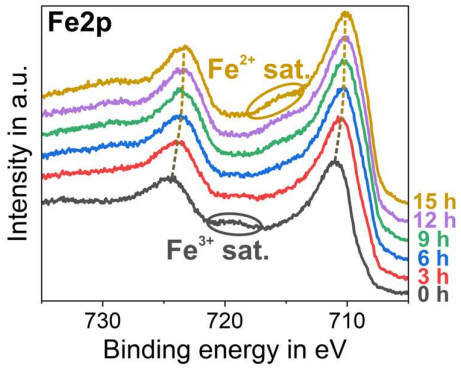


Figure 1. High-resolution Fe2p peak for hydrogen charging times over 15 h

# Low-chromium stainless steel SS430 and carbon steel B450C exposed to extract solution of green alternative cement

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Supersulfated “SS1” and sodium silicate-modified limestone “JLSC1” Portland cements have been proposed as an alternative for the partial replacement of the Portland cement clinker. The steels were exposed for 30 days to their aqueous extract solutions, simulating the concrete pore environment. The “SS1” initial pH of ~12.38 dropped since the first day to 7.84, while the “JLSC1” initial pH ~12.60 lowed to an average of 9.60. The pH changes were accompanied by a displacement to more negative values of the free corrosion potential (OCP) of the carbon steel, giving the formation of corrosion products of FeOOH, FeOOH and $Fe_2O_3$ as suggested by XRD and XPS analysis. In the meantime, the OCP of the SS430 tended to toward more positive values and a passive layer of $Cr_2O_3$ grew in the presence of FeO, $Fe_2O_3$ and $Cr(OH)_3$ corrosion products. The quantitative analysis of EIS Nyquist and Bode diagrams revealed that in “JLSC1” the Rp of the corrosion process for SS430 was ~32 times lower in magnitude than on B450C, for which the passive layer tended to disappear, while that on SS430 was ~0.83 nm.

# Prediction of multilayer Cr/GLC coatings degradation in deep-sea environments based on integrated mechanistic and machine learning models

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The prediction of coating performance and lifetime becomes a major challenge due to the complexity of coating failure in service environments. Multilayer structure amorphous carbon-based films have attracted attention for their high stability, hardness and corrosion-wear resistance, and have become a promising new material for metal protection in deep-sea environments. The failure mechanism of multilayer Cr/GLC coatings in the deep-sea environment was attributed to hydrostatic pressure increasing the dissolution rate of the metal transition Cr layer and the metal substrate, as well as hydrostatic pressure increasing the porosity of the coating. In this paper, based on in-situ electrochemical impedance spectroscopy data of multilayer Cr/GLC coatings, a lifetime prediction formula related to the coating failure mechanism is developed (Fig. 1), which provides a quantitative basis for estimating the coating lifetime. Furthermore, the combination of the mechanistic prediction model and the ANN+ RF integrated machine learning model can further increase the prediction accuracy of the model and reach 97.9% (Fig. 2), and provide a new method for predicting coating performance and lifetime in deep-sea environments.

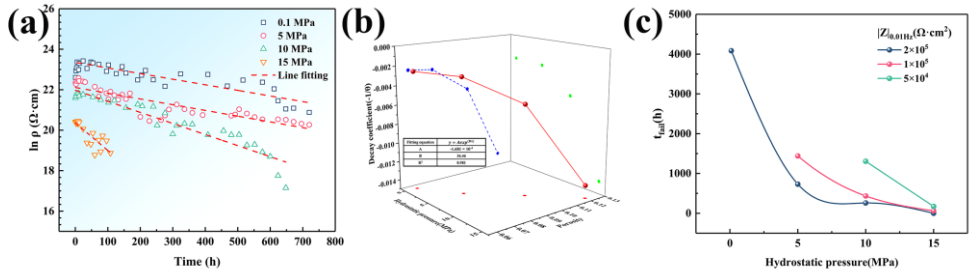


Fig. 1 Mechanistic empirical modelling of multilayer Cr/GLC coatings at different hydrostatic pressures for lifetime prediction (a) The resistivity of coating as a function of exposure time; (b) the relationship between porosity and attenuation coefficient of coatings; (c) Coating lifetime failure evaluation

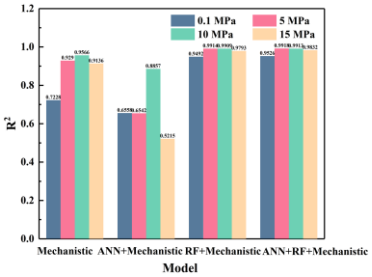


Fig. 2 Evaluation metrics $R^2$ for mechanistic empirical models, ANN + mechanistic, RF + mechanistic, and ANN + RF + mechanistic integrated models

# Studying the impact of Migrating Corrosion Inhibitors on enhancing durability in concrete pontoons, along with evaluating the effectiveness of concrete sensors employing electrochemical methods in marine environments

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**Abstract:**

The corrosion of embedded steel stands is a primary factor contributing to the decay of reinforced concrete structures. Despite advancements in concrete mix designs to enhance durability, the potential for cracking remains a concern, arising from factors such as shrinkage, movement, or external forces during the design process for prolonged service life.

The prevailing migrating inhibitor admixtures predominantly utilize amino carboxylate chemistry, with the most potent inhibitors demonstrating simultaneous interaction at both the anode and cathode.

This paper aims to provide an overview of the potential of admixed organic migrating corrosion inhibitors and their performance in construction of concrete pontoons.

It will also present an overview of the existing European standards in this context.

Electrochemical techniques are widely employed for corrosion studies due to their sensitivity and ability to provide real-time information.

Concrete corrosion monitoring sensors play a crucial role in assessing the structural health of concrete over time. Various types of sensors are employed for corrosion monitoring in concrete structures. This paper also revolves around the development of sensors employing electrochemical impedance spectroscopy for corrosion monitoring in concrete structures.

Keywords: migrating corrosion inhibitors, service life, concrete pontoons, reinforcement, electrochemical test, impedance spectroscopy, sensors

# New insights into the influence of tensile stress on the corrosion of high strength steel in deep sea environments

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## Background

High strength martensitic steels show promising mechanical properties, and has been extensively applied in the deep-sea structure.

In this work, Ni-Cr-Mo-V steel was used to study the synergistic actions of hydrostatic pressure and tensile stress on the early corrosion. It shows that pressure and deformation facilitate metal dissolution in the anodic process; Tensile stress thins the electric double layer, similar to the effect of hydrostatic pressure, resulting in the promotion of anodic reactions of the steel; The anodic current density calculated by the change of double-layer capacitance under tensile stress is approximate to that calculated by Gutman's theory.

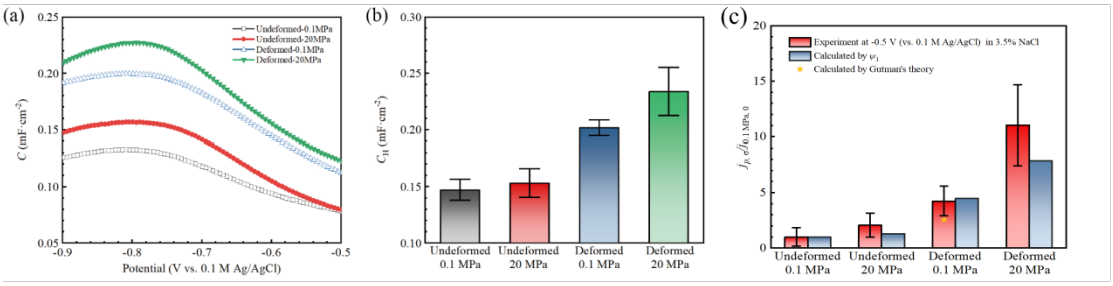


Fig.1 Differential capacitance and the calculated current density of Ni-Cr-Mo-V alloy. a) differential capacitance, b) the Helmholtz layer capacity under different conditions, and c) comparison of $j_{p,\sigma}/j_{0.1MPa,0}$.

# Attain insensitivity to chlorine ions in magnesium alloys by impeding the diffusion process

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To serve in a more aggressive chlorine ($Cl^-$) ions-containing environment, a chlorine ions insensitivity Mg-Nd-Zr alloys is fabricated, exhibiting a stable corrosion resistance in either 3.5wt.% or 10 wt.% NaCl solution. Unlike pure Mg who exhibit a negligible protection of the matrix, a distinct "hindering effect" of $Cl^-$ diffusion caused by doping elements within the corrosion film was observed. Its underlying mechanism is demonstrated by X-ray photoelectron spectroscopy (XPS) and Density functional theory (DFT) analysis. The introducing with Nd and Zr elements can effectively passivate vacancies and alter diffusion energy of chlorine ions.

# The Effect of Heat Treatment on the Microstructure and Corrosion Resistance of 55AL1Mg coating

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**Abstract：** Zn-AL-Mg coated steel is expanding its application due to its superior corrosion resistance compared to traditional galvanized steels such as GA and GI. During the use of Zn-AL-Mg coated steel plates, thermal environments such as spraying, cutting, and welding may be encountered. If the coating is damaged by heat, its corrosion resistance may decrease. However, detailed research has not yet been conducted on the thermal effects of coatings. This article selected three different temperature ranges, 300 ℃, 500 ℃, and 700 ℃, to heat treat the 55AL1Mg coating and keep it warm for ten minutes. Studied the phase transition process of coatings. And evaluate the corrosion resistance of the coated steel plate under the influence of heat. The results showed that for the coating structure of 55Al1Mg, when heated at 500 ℃, the area of the zinc rich phase significantly decreased and was replaced by the aluminum rich phase. In the heating range of 700 ℃, the microstructure underwent significant changes, resulting in columnar aluminum rich phases growing from the substrate, densely growing at the interface between the steel plate and the coating, and occasionally visible zinc rich phases at the grain boundaries. The XRD results also well demonstrate that 48% Fe4 Zn9 was generated at a heating temperature of 700 ℃, which is consistent with the observation results of electron microscopy.The results of electrochemical testing showed that for the 55Al1Mg coating, the corrosiveness first increased and then decreased, and the reason for this was the formation of a dense layer of oxide on the surface.

**Keywords:** Zn-55AL-1Mg, corrosion performance, eutectic structure, Fe4 Zn9

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