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Theoretical and experimental evaluation of organic compounds as corrosion inhibitors of copper in acidic media

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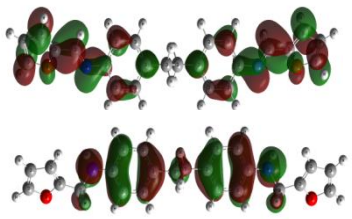
Abstract

Electrochemical techniques, SEM and theoretical calculation methods studied the inhibition effect of two compounds on the corrosion of copper 1.0 M HCl solution. The experimental results show that the two compounds are good inhibitors for copper in 1.0 M HCl.
Quantum chemical calculations based on DFT method were performed on two schiff bases compounds, used as corrosion inhibitors for copper in HCl media to determine the relationship between the molecular structure of schiff base and inhibition efficiency. Quantum chemical parameters such as the highest occupied molecular orbital energy (E_{HOMO}), the lowest unoccupied molecular orbital energy (E_{LUMO}), energy gap (ΔE), dipole moment (l), electronegativity (v), electron affinity (A), global ionization potential (I), the fraction of electrons transferred (ΔN), and the total energy (T_E), were calculated. The theoretically obtained results were found to be consistent with the experimental data reported.

Keywords: Optimization, DFT, Quantum chemical



Frontier molecule orbital density distributions using DFT at the B3LYP/6-31G (d,p). Top: HOMO, bottom: LUMO of (L) and protonated structure (HL)

Stress corrosion crack initiation of Type 304 stainless steel in simulated primary water

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Type 304 stainless steel (SS) is widely used in the primary coolant system of pressurized water reactors. However, the susceptibility of 304 SS to stress corrosion cracking (SCC) in this environment necessitates repair or replacement, resulting in significant economic losses. Understanding the SCC process is very important for preventing SCC failure. The SCC process comprises crack initiation and growth stages. Precisely differentiating crack initiation from growth using experimental methods is difficult, because crack initiation lacks a quantitative definition in terms of crack size. In this study, a crack length of less than 0.1 mm, as measured at the surface, is regarded to be indicative of the initiation stage. This investigation into SCC initiation in 304 SS employed the slow strain rate method, using flat tensile specimens with a gauge length of 9 mm in simulated primary water of a pressurized water reactor. The materials used in the initiation study included as-received material, 20% and 35% cold-worked material, and weldments. Initiation specimens were subjected to a strain of up to 10% with an initial strain rate of 1.85×10^{-7}/s in primary water of 325^{o}C, after which the straining was stopped, and the test loop was cooled to ambient temperature. The specimens tested in the loop were examined using SEM and EBSD. The cracking planes of SCC at the surface exhibited an almost normal orientation to the loading axis. Crack initiation occurred at grain boundaries between austenite grains, phase boundaries between austenite and ferrite grains, and the (111) crystallographic plane. The initiation paths varied with microstructures, and these are discussed in detail.

Rosemary water extract vs Rosemary essential oil as green corrosion inhibitor for mild steel

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Metallic materials are a vital part of today's industry and our day-to-day life. Among these mate-rials mild steel has good mechanical properties and is affordable. However, it is prone corrosion during the acid pickling surface treatment, as part of the manufacturing process. The most efficient solution to reduce metal loss due to corrosion and protect the metal surface from overcorrosion is the addition of corrosion inhibitors to the pickling solutions. The majority of the inhibitor used in today's industry are composed of chromates, molybdates, vanadates, and tungstates, and they have been discovered to have varying degrees of toxicity in relation to the environment. Therefore, new substances have been investigated in an effort to address this issue, comply with environmental regulations and adhere to the principles of green chemistry. They are distinguished by their exceptional efficacy and potential for low toxicity, as is the case with plant extracts, namely rosemary byproducts which are the purpose of this research. Corrosion behaviour is tested by potentiodynamic polarization and electrochemical impedance spectroscopy for 3 concentrations (1%, 2%, 3%) of water-based rosemary extract (WBRE), rosemary essential oil (REO) and a Blank sample. The mechanism of inhibition is also investigated by fitting the electrochemical data to multiple adsorption isotherm models. Preliminary results show that there is no significant difference between the 2 extract even though the extraction methods greatly differ. The findings of this study suggest that water-based rosemary extract can be used as a cost-efficient corrosion inhibitor, the extraction method being simple and not requiring special industrial machinery.

High-temperature Oxidation Behavior of Cr-Ni-Mo steel as ESR Electrode

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Objective: Cr-Ni-Mo alloyed steel ingots are used as electrodes to produce axle products under an ESR process.The temperature is high in the crystallizer thus large amount of electrode scale formation leads to an increase in FeO content in the slag and oxygen content in the product.High temperature oxidation kinetics of Cr-Ni-Mo axial steel under 800-1300℃ were investigated to determine the deoxidation process in ESR.Compositions of alloys is shown in Table 1.Samples were heated by a synchronous thermal analyzer in the air.

Table 1 Chemical composition (mass fraction) of experimental materials

Sample	C	Si	Mn	Cr	Ni	Mo	Fe
23CrNi3Mo	0.23	0.30	0.65	1.30	3.0	0.3	Bal.
40CrNiMo	0.40	0.25	0.7	0.8	1.4	0.2	Bal.

Results: Figure 1 shows typical morphology of scale after oxidation under 1150℃. Figure 2 shows the oxidation weight gain curves under different temperatures.

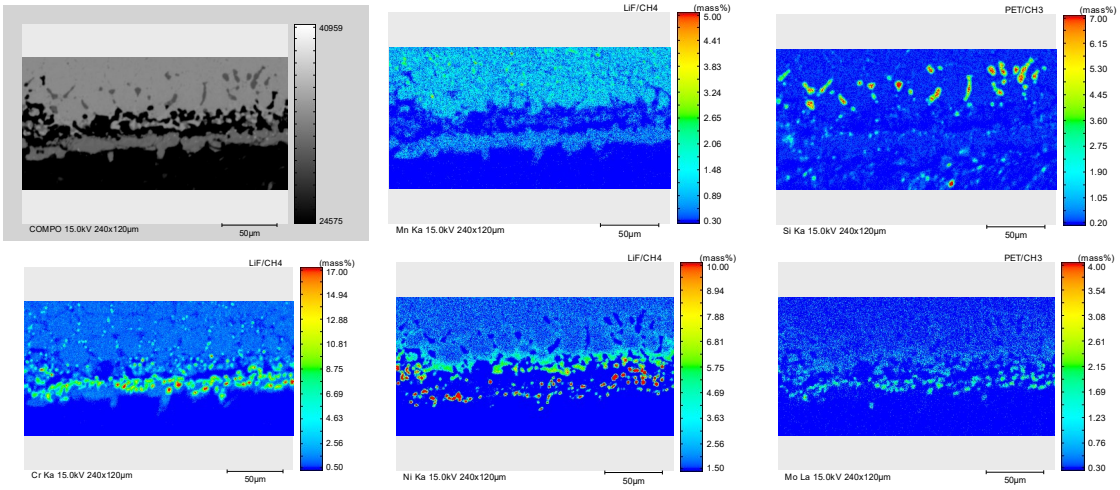

Fig. 1 Typical morphology of scale at 1150℃ for 30 minutes

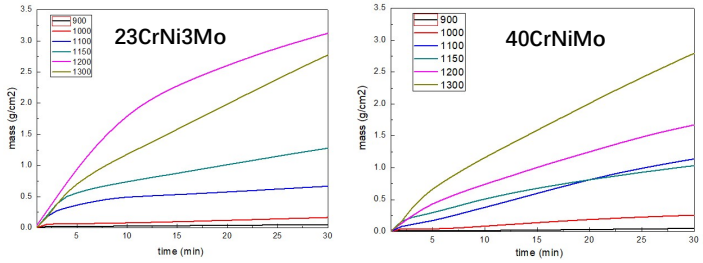

Fig. 2 Oxidation weight gain curves of Cr-Ni-Mo alloying steels

Ni and Cr can inhibit electrode oxidation under 1000℃. When the temperature increases to 1000℃, the oxidation rate was improved relatively low due to Ni mesh obstruction. It is only after 1200℃ that the oxidation rate has significantly increased.Based on the Cr-Ni-Mo steel oxidation kinetics, 7.5g aluminum particles are added into the ESR slag per minute to reduce the oxide in the electrode scale.

High-temperature Oxidation Behavior of High Cr Alloys

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Objective: Cr is widely used in stainless steels and high temperature alloys.High temperature oxidation behavior of 3%,5% and 9% Cr content alloys under 1100-1200℃ was investigated, providing a theoretical basis for the heating furnace processes for these alloys.Compositions of alloys is shown in Table 1.Samples were heated by a synchronous thermal analyzer under 2%O_2+98%Ar. Weight gain method was applied to study the oxidation behavior.

Table 1 Chemical composition (mass fraction) of experimental materials

Sample	Si	Cr	Fe
3%Cr	0.25	3.0	Bal.
5%Cr	0.25	5.0	Bal.
9%Cr	0.25	9.0	Bal.

Results: Figure 1 shows the morphology of three specimens after oxidation under 1100℃. Figure 2 shows the oxidation weight gain curves under different temperatures. According to Arrhenius equation,rate constant of metal oxidation $k = A\exp(-\frac{E_a}{RT})$,where Ea is the apparent activation energy.The smaller the Ea value, the poorer the oxidation resistance of the alloy.

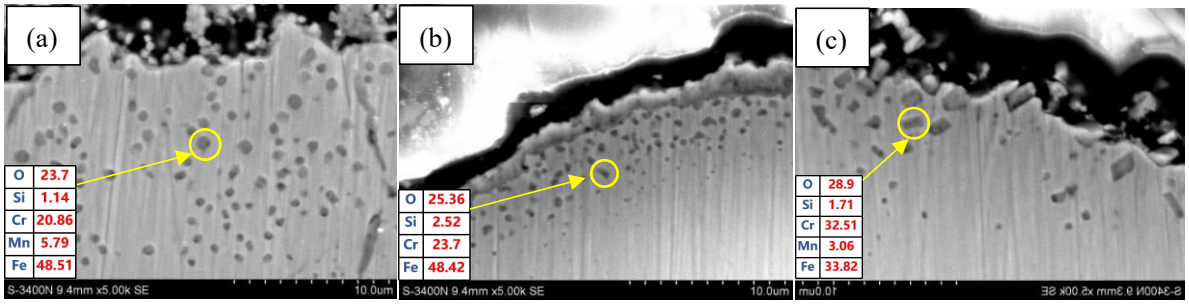

Fig. 1 Morphology and Compassion(wt%) of steel at 1100℃ for 30 minutes. (a)3%Cr,(b)5%Cr,(c)9%Cr

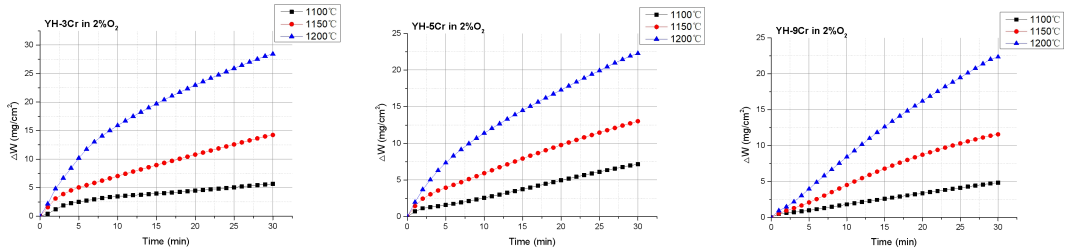

Fig. 2 Oxidation weight gain curves of Cr alloys. (a)3%Cr,(b)5%Cr,(c)9%Cr

Table 2 High temperature oxidation kinetics of experimental materials

Temp.,℃	3%Cr		5%Cr		9%Cr	
	k,mg²·cm-4/min	Ea,kJ/mol	k,mg²·cm-4/min	Ea,kJ/mol	k,mg·cm-²/min	Ea,kJ/mol
1100	0.51	123.05	0.87	180.41	0.16	256.07
1150	3.37	123.05	2.88	180.41	0.40	256.07
1200	13.98	123.05	8.51	180.41	0.77	256.07

The high-temperature oxidation process of 3% and 5% Cr alloys follows a parabolic pattern, while 9% Cr follows a linear pattern. Based on the oxidation kinetics of alloys as shown in table 2. As the Cr content increases, the oxidation resistance increases.

Slurry coating development for hydrogen-fired gas turbines.

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Abstract

Gas turbines operate under extreme conditions, with blades and nozzles in the hot section exposed to high temperature combusted gas carrying oxidative and potentially corrosive species. As the blades/nozzles are often cool, relative to the combusted gas passing them, there is a driving force for condensation of deposits onto their surfaces, potentially fluxing away protective oxidates. Changing fuels to meet net zero targets, for example, hydrogen, can affect the balance of oxidation and corrosion mechanisms, meaning that current understanding of their rates is less applicable.

Coatings are key in helping to minimise degradation mechanisms. Environmentally resistive coatings, potentially containing increased levels of chromium and aluminium, can help make more durable oxide scales and so increase resistance to these degradation mechanisms. However, blades/nozzles have complex geometry. As such, methods of coating need to be conformal.

Slurries have the potential to be applied to complex geometries and can result in uniform coatings. This work assesses the impact of substrate chemistry and slurry application parameters on the final coating uniformity. The coating has been assessed by electron microscopy to determine the thickness and composition. The mechanical performance of the coating has also been assessed using scratch testing and microhardness testing.

Studying fireside corrosion on heat exchanger materials in waste-to-energy power plants: Real case studies

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Abstract

Waste-to-energy (WtE) power plants and waste incinerators are on the rise in the UK and globally using agriculture and domestic waste, typically biomass as a main source of fuel. These plants have been accepted globally to generate power, preserve fossil fuels, and produce an eco-friendly environment by reducing the amount of greenhouse gases. Considering the Paris Agreement carbon emissions should reach net zero around the mid-century. These WtE power plants have proved to be a solution and data showed a significant reduction (5.2%) in greenhouse gases during 2022 in the UK. However, high levels of chlorine (Cl) and moisture content in biomass ash deposits found to be so destructive, trigger high-temperature corrosion in WtE power plants which ultimately results in heat-exchanger (HX) tube failure.

This paper summarises an ongoing work of a detailed examination of samples acquired from two different WtE power plants (case studies A & B) using different types of waste, effectively different combustion environments. The samples include failed tubes and ash deposits from each plant. The polished cross-sections were prepared and studied using scanning electron microscopy coupled with energy-dispersive X-ray provides details of microstructure, scale thickness, and distribution of elements across the scale. These results will be used to conclude possible corrosion mechanisms. The XRD was employed to study ash deposits and reveal corrosion compounds. A thermodynamic software FactSage will be used to generate phase diagrams of metal scale formation in different environments and support the data acquired for the failure analysis conclusion.

Study on the Influence of Chemical Compositions of low carbon steel on corrosion behavior in various acid concentrations

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Because of environmental problems are emerging as an internationally important issue, regulation to limit Sox, Cl and dioxin emissions of power plant is becoming tougher recently. Furthermore, with the increase of demand in energy efficiency, temperature of flue gas generated in thermal power plant is getting lower consistently. Recently, many researchers reported that not only sulfuric but hydrochloric acid can be condensed onto the steel surface with the aid of low flue gas temperature below HCl dew-point temperature. Additionally, when the exhaust gas temperature decreases, the concentration of acid generated in gas emission system due to water condensation gradually deceases.

For this reason, there have been continuous demands for materials that can cope with various corrosive gas environments in plant facilities. In this study, we aim to investigate the changes in corrosion behaviors based on the type and concentration of acid in low-carbon steel, as well as the influence of alloying elements on the corrosion behaviors. Through this study, we intend to provide fundamental data for alloy design that can exhibit corrosion resistance in various acid-corrosion environments.

Effect of alloy composition on the stress corrosion cracking susceptibility of single crystal nickel-based superalloys at 650°C

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1. Abstract

Industrial gas turbine blades are exposed to high stresses, salt deposits and high temperature sulphur containing atmospheres which can lead to stress corrosion cracking (SCC). Some fuels contain high concentrations of sulphur impurities, which can cause significant degradation to hot gas path components. Also, the effect of Cr concentration in the alloy can have a significant effect in reducing the rate of corrosion attack and extending the "time to cause stress corrosion cracking" in hot gas path components; hence an understanding of its effect is critical. This study investigates the effect of Na_2SO_4 and a 10000 ppmw SO_2 – air atmosphere on the stress corrosion cracking susceptibility of CMSX-4 (alumina former) and Y83 (chromia former) at 650°C and at stress levels ranging from 200 MPa to 800 MPa. The key objectives of this study are to understand the corrosion mechanisms caused by Na_2SO_4 in a 10000 ppmw SO_2 – air atmosphere at 650°C and understanding the role of Cr concentration on the stress corrosion cracking susceptibility of single crystal nickel-based superalloys.

A C-ring test method was used throughout this study, and characterisation techniques such as x-ray computed tomography (XCT), optical microscopy (OM) and scanning electron microscopy (SEM) were used to determine the crack initiation time of the two alloys as a function of stress and for the characterisation of the scales. The results so far highlight that CMSX-4 undergoes SCC with cracks extending through the 1.6 mm thickness of the C-ring within the first 50 hours of exposure, whereas Y-83 shows no cracking. These results are important to optimise the selection of suitable alloys and develop more accurate lifing models for industrial gas turbine blades in atmospheres containing SO_2 levels of 10000 ppmw.

Long-term corrosion and high temperature oxidation experiments of $M5_{Framatome}$ alloy in VVER conditions

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$M5_{Framatome}$* zirconium alloy is used as cladding reference material for the new VVER Fuel Assembly designed and developed by Framatome for licensing in Czech Republic. Corrosion tests demonstrated a satisfying behaviour in simulated VVER out-of-pile experiment. Long-term corrosion and high temperature oxidation experimental programs were launched in 2020 in close collaboration with UJP Praha to support the licensing of $M5_{Framatome}$ cladding with the Czech Republic's safety authorities. This work demonstrates excellent behaviour of $M5_{Framatome}$ cladding in out-of-pile corrosion experiments in representative VVER normal operating conditions and during high temperature steam oxidation representative of accident conditions.

The long-term corrosion experiment using a static autoclave at 360°C and VVER water-like chemistry was started in 2020. Currently, close to 1000 days of exposure have been reached. The $M5_{Framatome}$ cladding's corrosion behaviour and the microstructure were characterized at various intervals during the experiment, including hydrogen pick-up. The oxide layer thicknesses were calculated from the weight gain and compared with measurements from metallographic cross-sections and eddy current measurements.

High temperature oxidation tests in steam were performed on as-fabricated and pre-hydrided $M5_{Framatome}$ cladding and the post-quench ductility was assessed by means of ring compression tests. The weight gains measured by UJP Praha found the Cathcart-Pawel correlation is conservative with no signs of breakaway oxidation observed, even for extended durations at 1000°C. The good post-quench ductility of the $M5_{Framatome}$ alloy has been demonstrated by comparison with the US NRC DG-1263 acceptable limits for embrittlement during a loss-of-coolant accident.

These results demonstrate the $M5_{Framatome}$ alloy's good long-term corrosion and high temperature oxidation performances in VVER conditions in accordance with Framatome's existing experience and support its future implementation in VVER reactors.

Crevice Corrosion and SCC Behavior of iSMR Structural Materials in Simulated Primary Boron-free KOH Coolant

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The coolant chemistry proposed for iSMRs is different from the traditional LWR coolant, that is the boron-free and KOH addition for a pH control. An evaluation of the use of KOH as a replacement for LiOH in the boron environment has been performed based on a Vodo-Vodyanoi energetichesky reactor (VVER). According to VVER experience, the boron-KOH coolant shows good corrosion resistance with the stainless steel (STS) and the the Zr-alloy fuel cladding in terms of the general corrosion, compared to the boron-LiOH coolant. However, no studies on iSMR structural materials in boron-free environments containing KOH have been performed. In order to select the optimal material for iSMR, it is necessary to understand the relation between iSMR structral materials and boron-free KOH in the high temperature primary water environment.

This work aims to evaluate the crevice corrosion and stress corrosion cracking (SCC) behaviors of iSMR major component alloys, such as STS316L and Alloy 690, in the high temperature boron-free condition containing KOH. In addition, the dissolved hydrogen (DH) concenrtration tests to evaluate DH, which is one of the major factors affecting the SCC of Ni-based alloys, was conducted in the high temperature boron-free KOH condition. The crevice corrosion test was conducted by fabricating a device that simulates a crevice water chemistry environment to evaluate the crevice corrosion behavior of the STS316L material from an electrochemical perspective. The SCC test was conducted using an SSRT(Slow Strain Rate Test) in a simulated iSMR primary loop system to analyze the STS316L and Alloy690 materials. In this study, the corrosion tests of two materials were duscussed from the viewpoints of pH adjuster(KOH vs. LiOH) and DH concentration(25 cc/kgH_2O vs. 50 cc/kgH_2O).

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Corrosion Resistance of i-SMR Structural Materials in Boron-free Coolants with KOH and LiOH

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There is a growing interest in Small Modular Reactors (SMR) with outputs under 300 MW due to their versatile applications in energy sectors, including coal replacement, distributed energy systems, and hydrogen production. South Korea is actively developing an innovative Small Modular Reactor (i-SMR) featuring a boron-free core design, which enhances both safety and economic efficiency. This design significantly reduces liquid radioactive waste, mitigates crud-induced power shifts (CIPS), and simplifies the chemical and volume control system (CVCS) for boron control. Additionally, the use of Potassium Hydroxide (KOH) is being explored as an alternative pH control agent for the coolant, offering advantages in terms of both price and supply compared to the previously used Lithium Hydroxide (LiOH).

The Electric Power Research Institute (EPRI) has carried out extensive research to explore the use of KOH as a replacement for LiOH for the primary coolant system in commercial pressurized water reactors. Also, the VVER in Russia which utilizes KOH, has shown better corrosion resistance in stainless steel and zirconium alloy. However, previous studies focus on only borated water environments and cannot be directly applied to boron-free water. Thus, there is a need for new studies on corrosion characteristics in a boron-free environment.

This study aims to bridge this gap by evaluating and comparing the corrosion properties of key structural materials used in i-SMR, specifically focusing on 316L stainless steel, Alloy 690, and Zirconium alloy. The corrosion test was conducted in a simulated boron-free water chemistry loop system, using both KOH and LiOH as pH control agents. This includes examining corrosion rates, oxide film characteristics using SEM, XRD, FIB-TEM. Through this study, we aim to provide fundamental corrosion data, which is essential for ensuring the long-term durability and safety of i-SMR.

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Influence of yttrium oxide concentration on corrosion resistance of 316L oxide dispersion strengthened (ODS) steel

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High-temperature and harsh conditions require the use of advanced and highly resistant materials. Nuclear reactors are a very good example of an environment with such conditions, and oxide dispersion strengthened (ODS) 316L steel is suitable to build them. This is a material with desirable properties such as good workability, ductility, and mechanical integrity at very high temperature exceeding 1000 °C.

In this study, to improve the corrosion properties of 316L steel, yttrium oxide (Y_2O_3) was added to the matrix. Materials for this research were manufactured through pulse plasma sintering (PPS) and subsequently compared with the reference materials (316L commonly available rods). The corrosion resistance of the oxide dispersed strengthened austenitic 316L+Y_2O_3 was investigated. The concentration of Y_2O_3 was 1 wt. % and 3 wt. % in nano and micro size. The electrochemical tests and corrosion rate measurements were carried out to determine the corrosive properties. Next, the corrosion damage on the surfaces was characterized using scanning electron microscopy (SEM) and optical profilometry.

Keywords: ODS steel, corrosion properties, SEM

This research is funded by National Science Centre, Poland under the OPUS call in the Weave programme (project No. 2021/43/I/ST8/01018).

Electrochemical study of the influence of pH and carbonate concentration on the anodic dissolution of depleted UO2

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In the Belgium current “Supercontainer” design for the deep geological disposal of High Level Waste, SNF will be surrounded by an important amount of concrete. In this context, and because the dissolution of UO_2 is an electrochemical reaction, this work compares the electrochemical analysis of depleted UO_2 in alkaline and anaerobic conditions (pH 9 and 13.5) with or without carbonates (0 to 9.5 10^{-4} mol/L). In presence of carbonates, the open circuit potential is lower whatever the pH. This is in accordance with the evolution of the calculated mass loss with time. At pH 9 without carbonates, the corrosion rate is the lowest. The rate increases with the addition of 3 10^{-4} mol/L of carbonate in a solution at pH 13.5. Finally, increasing further the carbonate concentration to 9.5 10^{-4} mol/L, while the pH is decreased to 9 further increases the mass loss.

Deposition and stability of uranium oxide films for α-irradiation-electrochemistry experiments

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Canada plans to use a deep geological repository (DGR) system consisting of corrosion-resistant used fuel containers (UFCs) and other barriers for the safe and long-term management of spent nuclear fuel. While the UFC will provide long-term containment, it is necessary to consider the consequences of its failure which could lead to exposure of the fuel to groundwater. Most of the radionuclides in spent fuel are trapped inside the UO_2 grains, and the fuel corrosion will determine how fast they can be released. Assuming a reasonable containment period of nuclear fuel in containers prior to contact of groundwater with the fuel, α radiolysis will be the dominant source of oxidants.

This study investigates the interaction of α-particles with the fuel surface to figure out their effects on the UO_2 fuel corrosion/dissolution. The methodology is to perform in-situ α-irradiation-electrochemistry experiments using the Rutherford backscattering beamline in the Western Tandetron accelerator and sealed radiation sources to provide a constant flux of high-energy α-particles. The specific experimental setup required for this study prevents the direct usage of UO_2 fuel pellets. Instead, using the electrodeposition technique, uranium oxide thin films were grown on metallic foil substrates. An aqueous electrolyte containing uranyl nitrate as the uranium source was used for this purpose. Films were grown using current densities of 5-30 mA/cm^2, pH = 7.5 to 8.5, and 76 ± 1 °C temperature.

To make sure the composition of the deposited films matched the composition of the used fuel, a detailed characterization of the films was performed. SEM analysis revealed a cauliflower-like morphology for the films, and the presence of uranium and oxygen was confirmed through EDX analysis. RBS measurements showed that the films have a thickness of a few micrometres. XRD patterns obtained from samples showed a broad peak at around 28°, indicating the amorphous structure of the films. Raman analysis revealed the presence of peaks related to U_4O_9 and U_3O_8 phases. Investigations of the effects of annealing on the properties of the films, and studies of alternative deposition solutions, are currently underway to obtain the desired film for the α-irradiation-electrochemistry experiments.

RESULTS FROM CORROSION TESTS PERFORMED IN ECC-SMART PROJECT

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ECC-SMART (*Joint European Canadian Chinese development of Small Modular Reactor Technology)* focuses on developing Small Modular Reactor (SMR) technology using Supercritical Water (SCW) as coolant, offering versatility and safety benefits over traditional Light Water Reactors (LWRs). ECC-SMART Work Package 2 (WP2) studies corrosion behavior of candidate cladding materials. Alloys like Alloy 800H, Stainless Steel 310S (both purchased in tube shape to investigate the effect of forming on material corrosion resistance) and Alumina Forming Austenitic (AFA) alloy were tested under SCW-SMR simulated conditions: 380ºC, 500 ºC, 25 MPa and 23 MPa (in limited number of tests to explore the influence of pressure) and 150 ppb of oxygen. In addition to this, corrosion tests with pre-irradiated materials in the research reactor LVR15 located at CVR in the Czech Republic were conducted to understand neutron irradiation effects on material corrosion in SCW.

The aim of this work is to present ECC-SMART and its WP2 more in detail to the corrosion community, as well as showing selected results from the corrosion tests performed in SCW-SMR simulated conditions.

Study for corrosion behavior of ODS austenitic steels with Y_2O_3 addition during salt spray test

***Marlene Gonzalez*[1], *Anna Dobkowska*[1], *Aleksandra Zielińska*[1]**

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Austenitic stainless steels are important structural materials for oil field equipment, ship power system and pressurized-water reactor nuclear-power plant applications. However, they are easily damaged by intergranular corrosion, stress corrosion cracking and corrosion fatigue. One way to improve its properties is the addition of nano reinforcers as in oxide dispersed-strengthened (ODS) steels.

ODS steels are mostly produced through powder metallurgy (PM) which includes preparation of powders by mechanical alloying (MA) in a high-energy ball mill [1].
In this study, oxide nanoparticles as Y_2O_3 were dissociated into the matrix of the 316L stainless steel powder.

The main goal of this work was to analyze the corrosive behavior of the austenitic 316L stainless steel with the addition of 1 wt.% of two sizes of Y_2O_3. The materials were manufactured from powders prepared under different conditions (time and intervals of mechanical alloying). Test specimen were subjected to salt spray testing in accordance with EN ISO 9227:2017 *Corrosion tests in artificial atmoshpheres – salt spray tests*. Afterwards, the surface degradation was analyzed and deeply examined using surface sensitive techniques.

[1] L. Raman et al., Def Science J. 66 (2016) 316–322.

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Investigating Cu Corrosion Behavior Under Anaerobic Conditions and Temperature Gradients

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Abstract: Copper (Cu) is widely recognized for its corrosion resistance properties, making it an ideal material for canisters designed to store High-Level Radioactive Waste (HLW) in Deep Geological Repositories (DGRs). Despite its classification as a semi-noble metal, Cu can experience corrosion in anaerobic environments, particularly in the presence of sulphide ions, which act as potent oxidizing agents. Previous assumptions suggested that the period of oxic corrosion would span several hundred years, leading to a belief in Cu's long-term stability. However, recent field tests have revealed a rapid diminishment of oxic corrosion within a few years, raising concerns regarding Cu's susceptibility to corrosion under relatively high temperatures over extended periods.

This study aims to investigate the corrosion behavior of Cu under anaerobic conditions at elevated temperatures (25-75°C). Experimental setups employed gas-tight isolation of electrochemical cells within a glove box, ensuring precise control of variables. Corrosive solutions were prepared using sodium sulphide (0.01~1mM), sodium chloride (1~100mM), and borate buffer solution (0.02M) of at least ACS grade purity. Electrochemical measurements were conducted using a three-electrode system, with a potentiostat employed for anodic polarization measurements.

Results revealed a notable correlation between temperature and corrosion potential, with a decrease in corrosion potential observed as temperature increased. Additionally, an increase in chloride concentration corresponded to a decrease in the breakdown potential of passivation or porous film. These findings provide crucial insights into Cu's corrosion behavior under conditions resembling DGR environments, aiding in the preparation for corrosion-related challenges in DGR construction, particularly in the Republic of Korea.

Unraveling the influence of zinc water chemistry on oxide film characteristics of Alloy 182 in boiling water reactor environment

***Ting Wang*[1], Adrianna Mackiewicz[1], Hans-Peter Seifert[1], Thomas A. Jung[1], Christof Schneider[1], Stefan Ritter[1]**

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Zinc (Zn) injection into light water reactor (LWR) coolants has been widely utilized to reduce the radioactive build-up in the primary circuit. Recent studies [1, 2] have unveiled another beneficial effect of Zn injection in mitigating stress corrosion cracking (SCC) of structural materials. To gain deeper insights into the SCC mitigation mechanism, this work investigates the effect of Zn injection on the properties of the oxide layer developed on a nickel-based weld metal (Alloy 182) in boiling water reactor (BWR) environment.

Specimens were exposed to both Zn-free or Zn-containing BWR water in autoclaves (T = 274 °C, p = 90 bar) with recirculating water loops. Multiple characterization techniques, including electron microscopy, X-ray photoelectron spectroscopy and Raman spectroscopy were employed to analyze the oxide film characteristics before and after Zn treatment. The results reveal that Zn is incorporated into the inner and the outer oxide layer, probably as $(Zn_xNi_yFe_{1-x-y})Cr_2O_4$ of variable stoichiometry and $ZnFe_2O_4$. In parallel to the Zn accumulation, we observe the formation of a thinner and more compact inner oxide layer, which may enhance the protective properties of the material with regard to corrosion. This complex modification of the oxide film composition and structure is tentatively associated also with the observed SCC mitigation in Alloy 182.

Acknowledgements

The Swiss Federal Nuclear Safety Inspectorate (ENSI) is gratefully acknowledged for the financial support. Great thanks are expressed to Christian Zaubitzer and ScopeM at ETH Zurich, Hans Kottmann, Beat Baumgartner, Roger Schwenold, Elisabeth Müller, Markus Kropf and Narmadha Devi Suresh Kumar (all PSI) for their excellent experimental support.

[1] K. Chen, A. Mackiewicz, S. Virtanen, H.P. Seifert, S. Ritter, Role of Zn injection on mitigating stress corrosion cracking initiation of Alloy 182 weld metal in simulated light water reactor environment, Corrosion Science, 221 (2023) 111364.

[2] K. Chen, A. Mackiewicz, S. Virtanen, P.V. Grundler, H.-P. Seifert, S. Ritter, Effect of zinc injection on mitigating stress corrosion cracking initiation of structural materials in light water reactor primary water, Corrosion Reviews, 41 (2023) 387-398.

Corrosion of Carbon Steel Under Simulated Geological Repository Conditions

***Muhammad Faiz Al Rasyid Tisyadi*[1], Lola Sarrasin[1], Abdesselam Abdelouas [1], Guillaume Blain[1], Tomo Suzuki-Muresan[1], Johan Vandenborre[2]**

1) *SUBATECH (IMT Atlantique, CNRS/IN2P3, Université de Nantes), BP 20722, 44307 Nantes Cedex 3, France*
2) *Institut des Matériaux de Nantes Jean Rouxel Unité mixte de recherche CNRS 6502 - Université de Nantes, France*

Corrosion of canister material is an issue of importance in the long-term safety of a deep geological repository (DGR) of high-level radioactive waste (HLW). During storage, the corrosion behaviour of the metallic container is affected greatly by environmental parameters that evolves over time. Among those parameters are relative humidity (RH%), temperature, radiation, interaction with buffer materials, and the presence of oxygen. In the literature, corrosion of steel materials under humid air conditions in the context of DGR has not been thoroughly explored. Therefore, we have examined the effect of RH on the corrosion of carbon steel (P235GH) under anoxic conditions, and the impact of the presence of buffer material (MX80 bentonite). The samples were irradiated using a ^{137}Cs gamma source under varying total doses up to 400 kGy. The samples were tested in 63, 76, and 99% RH using salt solution for humidity control and kept in anoxic condition using Argon gas. After irradiation, H_2 gas production rate was measured with GC, corrosion rate was measured using the mass loss method, and corrosion phases are characterized by X-Ray Diffraction (XRD).

Results show that both H_2 gas and corrosion rate are highest in 63% RH and lowest in 99% RH, which suggests an acceleration of the corrosion in lower RH conditions. Results also show that corrosion rate and H_2 is higher in samples without bentonite, suggesting the presence of an inhibition effect by the clay. XRD phase analysis show that the corrosion phases obtained are mainly Iron Oxides (Magnetite), Iron Oxy-Hydroxides (Goethite, Lepidocrocite, and Akaganeite), and Iron Carbonates (Siderite). This work provides an insight towards the expected corrosion rates in the evolution of RH under irradiation and the presence of bentonite. This work also gives an insight on expected corrosion phases in such conditions. Overall, this work contributes to the knowledge base of corrosion under humid air conditions in the context of DGR.

Effect of the segregation band on the hydrogen embrittlement susceptibility of quenched and partitioned steel

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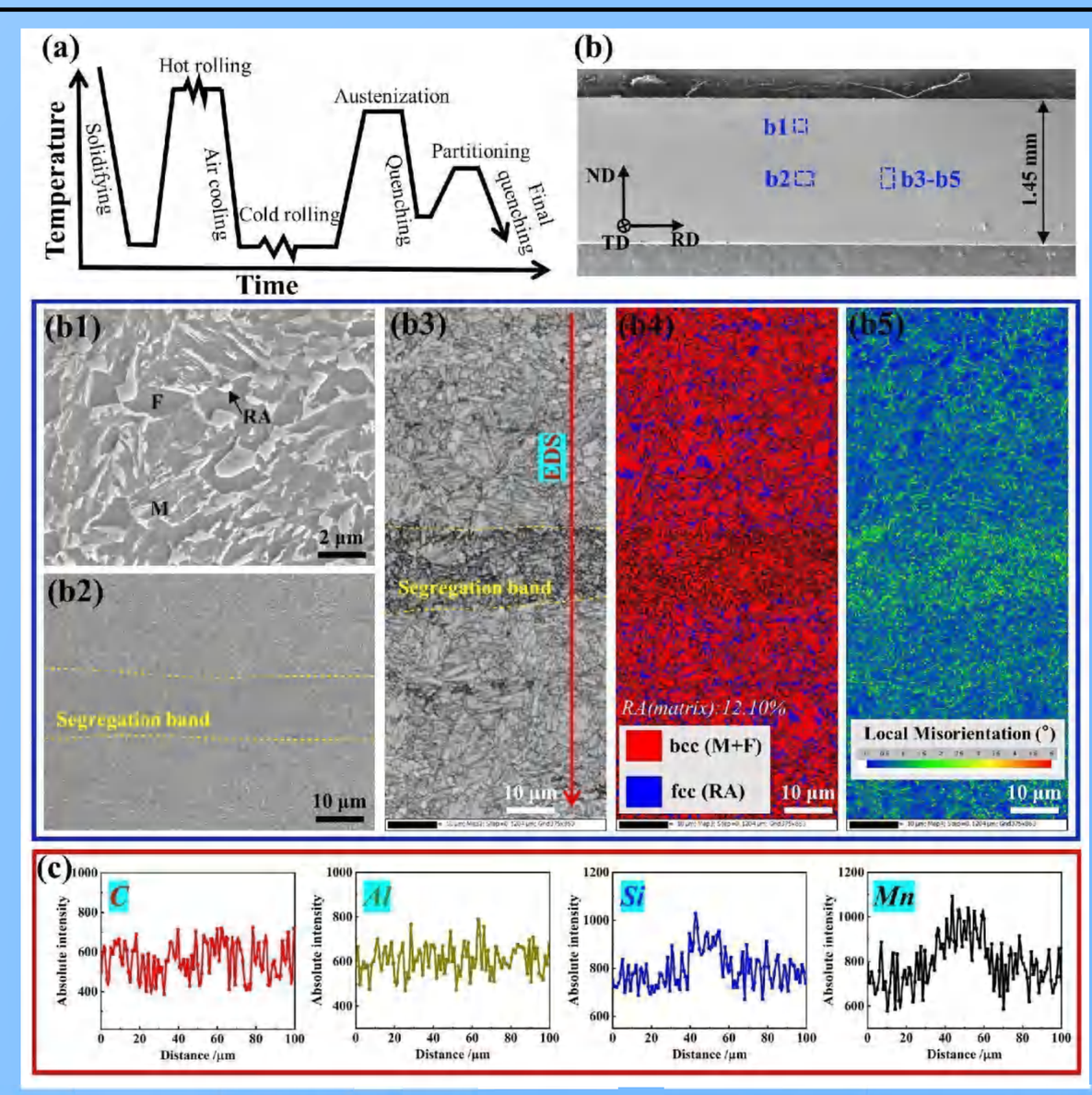
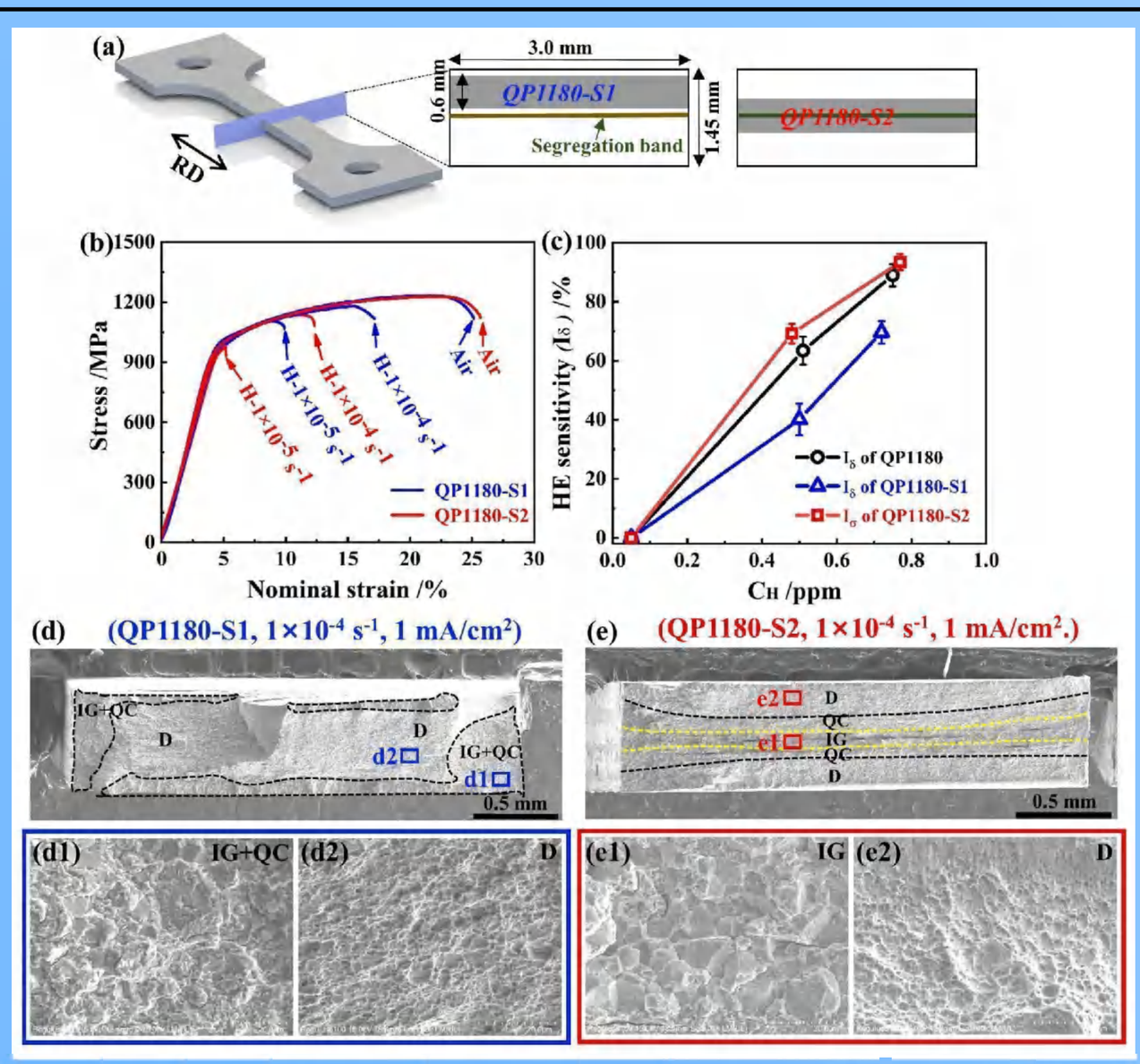
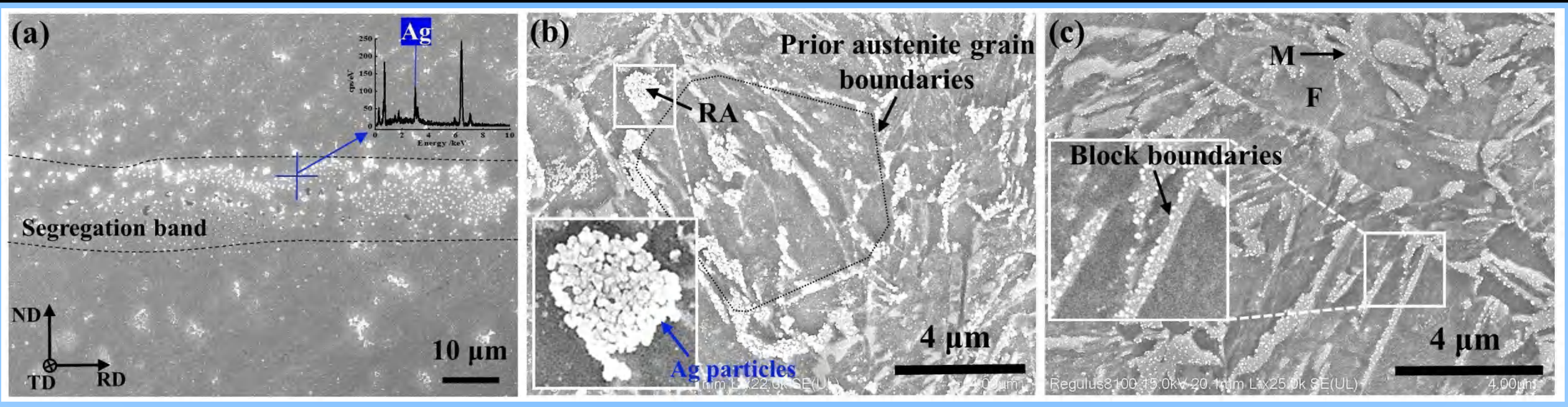
Abstract: Quenching and partitioning (Q&P) steels have been widely used in the automotive manufacturing industry due to their excellent strength and ductility. However, as the strength of these steels increases, the issue of hydrogen embrittlement (HE) becomes more severe. Current studies on HE in Q&P steels mostly assume the material to be homogeneous. However, in reality, there often exists a segregation band (SB) in the center thickness of Q&P steels, and the impact of this non-uniform microstructure on HE is not yet well understood [1].



The material studied in this paper is a commercial automotive steel sheet, QP1180, which exhibits a SB with a thickness of approximately 20-30 μm in the center of the sheet. The SB consists almost entirely of martensite and exhibits a high dislocation density. Additionally, visible elemental segregation of Mn and Si is observed within the SB.



SSRT tests with hydrogrn charging were conducted to evaluate HE sensitivity of the specimens, including full-thickness (1.45 mm) specimens, half-thickness (0.6 mm) specimens S1 without SB, and half-thickness specimens S2 containing SB. The results indicate that S2 exhibited higher HE susceptibility compared to S1. The presence of SB will reduce the HE resistance of Q&P steels.



The hydrogen microprinting (HMT) test was used to visualize the hydrogen, and the HMT results showed that a large amount of hydrogen was adsorbed in the SB. The SB consists of martensitic, which exhibits the highest HE susceptibility. Even at relatively low hydrogen levels, hydrogen-induced cracking is prone to occur.

Conclusions:

1. The presence of SBs will increase the HE sensitivity of QP1180.
2. The SB in QP1180 has a high dislocation density and adsorbs a large number of hydrogen atoms. The microcracks are nucleated on the SB, which reduces the HE resistance of QP1180.
3. The HMT tests show that the local hydrogen enrichment level in QP1180 is Segregation band > Retained austenite > Prior austenite grain boundaries > Block boundaries > Martensite > Ferrite.

[1] Weiguo Li , et al. Corrosion Science, 2023, 222: 111436.

Study to determine the root cause of the cracks detected in the frame reinforcement of a helicopter

***María García-Martínez*, Francisco Javier García de Blas Villanueva, José Miguel Álvarez, Marta Hernández Santandreu, Sergio Ulargui Diego**

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During a routinely inspection, several cracks were observed in a helicopter frame reinforcement. The said reinforcement was made of an Al2024 aluminum alloy in a T4 heat treated state and was coated both internally and externally with a typical aeronautical paint. This paper presents the study to determine the root cause of the appereance of the mentioned various cracks detected.

In order to delimit and characterize the existing damage, non-destructive tests (NDT), namely visual and radiographic inspections, were carried out on the whole frame reinforcement. In addition, a chemical analysis of material was performed by X-ray fluorescence and its hardness was determined. Fractographic studies were executed using a stereo microscope and a field emission scanning electron microscope (FE-SEM) equipped with energy dispersive spectrometry X-ray (EDX). The protective coating was studied by optical microscopy (OM) and FE-SEM and its semi-quantitative chemical composition was determined by EDX. To characterize the aluminium alloy microstructure, metallographic samples were prepared for observation by OM.

Macromorphological and micromorphological characteristics typical of stress corrosion cracking were observed in the fractographic study, such as the absence of plastic deformation, brittle fracture progressing with different steps and plane change of fracture progression, as well as an attacked surface with corrosion products with a "cracked mud" appearance. All above mentioned, besides the fact that the material of the frame reinforcement, Al2024-T4, is susceptible to stress corrosion cracking, suggested that this was the main fracture mechanism. In addition, this was consistent with the sustained compressive stresses to which the frame reinforcement was subjected on the left side and tensile stresses on the right side, due to the torque generated in the tail rotor.

Environment Sensitive Fracture (WP5)

A new maraging steel for aggressive environments: enhanced corrosion and hydrogen embrittlement resistance

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2) University of Oviedo, Gijón/Spain

3) ArcelorMittal, Avilés/Spain

Maraging steels are frequently used in aggressive environments when a good combination of high-strength, toughness and corrosion resistance is required. On the other hand, additive manufacturing, and especially laser-powder bed fusion techniques (LPBF) are being investigated as potential manufacturing routes for the production of high-responsibility maraging components in the aviation and aerospace industries. However, corrosion and hydrogen embrittlement, which affects especially high-strength metals such as maraging steels, could potentially hinder their safe implementation in these kinds of applications. Therefore, numerous efforts are underway to understand the complex interactions between hydrogen atoms and the complex Fe-Ni martensitic microstructure of maraging steels during their service in aggressive environments. Up to now, LPBF maraging has shown a considerable hydrogen embrittlement susceptibility, increased after the application of aging heat treatments, the main strengthening mechanism of the alloy. Therefore, in this work a new LPBF maraging steel grade patented by ArcelorMittal with reduced Ni and Co contents – to reduce production costs - is proposed as an alternative to conventional maraging. A comprehensive corrosion and hydrogen embrittlement characterisation of the new alloy, including hydrogen diffusivity measurements, hydrogen trapping analysis and tensile experiments has been conducted. Overall, the results indicate an improvement of the corrosion resistance and a reduction of the hydrogen embrittlement sensitivity, despite the higher hydrogen content measured in the alloy. T_herefore, future work will consider the effects of intermetallic strengthening in the corrosion and hydrogen embrittlement behaviour of the alloy, which could represent a cost-effective alternative for the manufacturing of maraging components for aggressive, hydrogen-rich environments.

Characterization of two austenitic stainless steels and their welds in fatigue and damage tolerance in hydrogen and cryogenic environment

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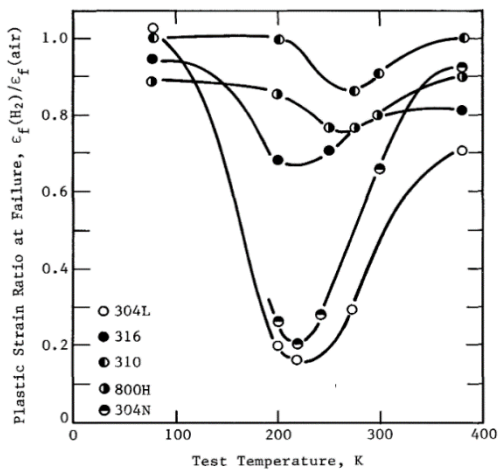
Keywords: Hydrogen Embrittlement, Austenitic Stainless Steels, Cryogenic temperatures, TIG welds, Fatigue

For decarbonated flights, Airbus investigate the use of Liquid Hydrogen (LH2) as an alternative to hydrocarbon fuel. This rises many challenges as regards the storage and the distribution of this new fuel. One of the points of attention is hydrogen diffusion and potential associated embrittlement of metallic materials. A resistant alloy commonly used for this type of application is the 316L austenitic stainless steel although this steel was originally not designed for this purpose. This would suggest that other alloys might achieved better resistance and global performance. In this study, two alternative grades of austenitic stainless steel will be characterized in that regard, in terms of tensile, fatigue and damage tolerance properties as a function of temperature. The main aim is to identify the worst case of embrittlement for those materials and compare them to 316L data from literature.

In order to justify LH2 storage compatibility, several test conditions will be investigated. Various tests such as Slow Strain Rate Tensile Tests(SSRTT), fatigue (R=0.1) or fatigue crack propagation test will be conducted in different environments and temperature in order to explore different hydrogen embrittlement cases. The case of weld joints will be also investigated.

In order to characterize Hydrogen Embrittlement (HE) resistance, tests will be performed with thermally precharged samples in air, to reach homogeneous hydrogen profile in samples, and tested in hydrogen environment, to provide hydrogen to the crack tip. Tests with both precharged samples and H_2 environment will also be performed. The HE will be mainly given by the Relative Reduction of Area (RRA) and elongation (RE) at rupture, as done by Lee et al. [1].

$$RRA = \frac{RA_{H2}}{RA}, \qquad RE = \frac{RE_{H2}}{RE}$$



These tests will be repeated at low temperature, down to ~205K, which is almost the critical temperature at which HE resistance is believe to be the lowest (150-250K), as seen in the figure on the left. [2]

All these tests will be performed again with the welded joint in the useful part of the specimens. Micrographic inspection will be done for every configuration to point out every phases and microstructures that could appear after testing in all these conditions: austenite, twins (TWIP), martensite (TRIP), delta ferrite, sigma phase and others.

Identifying the worst case of embrittlement is critical and will ensure a conservative design of a tank taking into account the presence of weldments.

Reference

[1] Lee, Hydrogen Embrittlement (2016)

[2] Caskey, Hydrogen compatibility handbook for stainless steels (1983)

Hydrogen Induced Stress Cracking of

High Strength Steel in mobile drilling rigs

***Harry Otteskov*[1], *Ditte Bilgrav Bangsgaard*[2], *Jeppe Havstrup*[3]**

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Our ever-increasing demand for energy is pushing our offshore structures and installations in size, operational requirements, and service longevity further. A large portion of these offshore structures relate to the exploration and production of hydrocarbons, which have similarly faced increasing demands. As drilling rigs must venture further into deeper waters, the requirements of more robust and weather resilient steel structures increases. An in-depth understanding of high strength steels with good weldability and advantageous mechanical properties is critical in mitigating the effects of environmentally induced cracking.

This short presentation will cover the key factors that influence the occurrence of Hydrogen Induced Stress Cracking (HISC) and its susceptibility to high strength steels exposed to offshore environments. For the purposes of this presentation, the high strength steels examined as cases for reference, was limited to jack-up drilling rigs, which were examined by FORCE Technology. The presentation will also cover good practices that can be implemented during the building of jack-up rigs, monitoring during operation and the implementation of mitigative measures to avoid downtime and extend service life.

CORROSION BEHAVIOR OF ZN-AL-MG ALLOY COATED STEEL IN RESIDENTIAL WATER

***Se-Young Oh*[1], *Jea-Won Lee*[1]**

1) POMIA (Pohang Institute of Metal Industry Advancement), Pohang, Gyeongbuk, Korea

This study evaluates the corrosion resistance of Zn-Al-Mg alloy-coated steel under normal residential water conditions and explores the corrosion behavior mechanism. The experiment involved observing the microstructure, conducting immersion tests on surfaces and cross-sections, and analyzing corrosion products for three commercially available coated steel samples: GI, Galvalume, and Zn-Al-Mg. The results indicate excellent corrosion resistance of Zn-Al-Mg, even under low chloride ion concentrations, ensuring long-term durability of the alloy-coated steel. Particularly, the corrosion products of Zn-Al-Mg consist of a composite composition of $Zn_5(OH)_8Cl_2 \cdot H_2O$ and $Zn_5(OH)_6(CO_3)_2$, suggesting a positive role in long-term corrosion resistance. This research provides new insights into the corrosion resistance evaluation and corrosion behavior mechanism of alloy-coated steel in environments with low chloride ion concentrations, emphasizing the outstanding corrosion resistance of Zn-Al-Mg alloy-coated steel, even in low chloride environments such as residential water.

Keyword: Zn-Al-Mg alloy-coated steel, Corrosion resistance, residential water, immersion tests, corrosion behavior

CORROSION BEHAVIOR OF ZN-AL-MG ALLOY COATED STEEL IN DOMESTIC WATER

***Se-Young Oh*[1], *Jea-Won Lee*[1]**

1) POMIA (Pohang Institute of Metal Industry Advancement), Pohang, Gyeongbuk, Korea

This study evaluates the corrosion resistance of Zn-Al-Mg alloy-coated steel under normal residential water conditions and explores the corrosion behavior mechanism. The experiment involved observing the microstructure, conducting immersion tests on surfaces and cross-sections, and analyzing corrosion products for three commercially available coated steel samples: GI, Galvalume, and Zn-Al-Mg. The results indicate excellent corrosion resistance of Zn-Al-Mg, even under low chloride ion concentrations, ensuring long-term durability of the alloy-coated steel. Particularly, the corrosion products of Zn-Al-Mg consist of a composite composition of $Zn_5(OH)_8Cl_2 \cdot H_2O$ and $Zn_5(OH)_6(CO_3)_2$, suggesting a positive role in long-term corrosion resistance. This research provides new insights into the corrosion resistance evaluation and corrosion behavior mechanism of alloy-coated steel in environments with low chloride ion concentrations, emphasizing the outstanding corrosion resistance of Zn-Al-Mg alloy-coated steel, even in low chloride environments such as residential water.

Keyword: Zn-Al-Mg alloy-coated steel, Corrosion resistance, residential water, immersion tests, corrosion behavior

Study on corrosion behavior of Zn-Al-Mg materials under VDA621-41 test

***Min Li*[1], *Rong Shao*[1], *Jianping Cao*[1], *Xuetao Li*[1], *Yongzhuang Liu*[1]**

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Abstract At present, zinc alloy coating for automobile body mainly includes hot-dip galvanized material (GI) and Zn-Al-Mg coating material (ZM). GI sheet refers to zinc alloy coated steel sheet formed by hot-dip galvanizing of strip steel with aluminum content of 0.11%~0.14% and then cooling by air knife, and the coating structure is mainly composed of pure zinc phase. ZM material is a kind of zinc-based coating with magnesium and aluminum added, which changes the structure of the coating, and ZM material has better corrosion resistance. Automotive panels are generally used in combination with coatings, and corrosion protection mainly consists of pretreatment films and electrophoretic films. The corrosion resistance of the electrophoretic paint film of galvanized sheet after being damaged is the key to the corrosion protection of the whole vehicle. In this paper, the corrosion resistance of GI and ZM plates after painting was compared, and the hanging pieces were painted in nine different pretreatment bases and tested by VDA621-415 cyclic corrosion standard. The results show that the width of unilateral corrosion expansion of ZM materials is smaller than that of GI materials. Sample C and H (both ZM and GI) which using phosphating process show smaller corrosion expansion width than that of other samples which using thin film process.

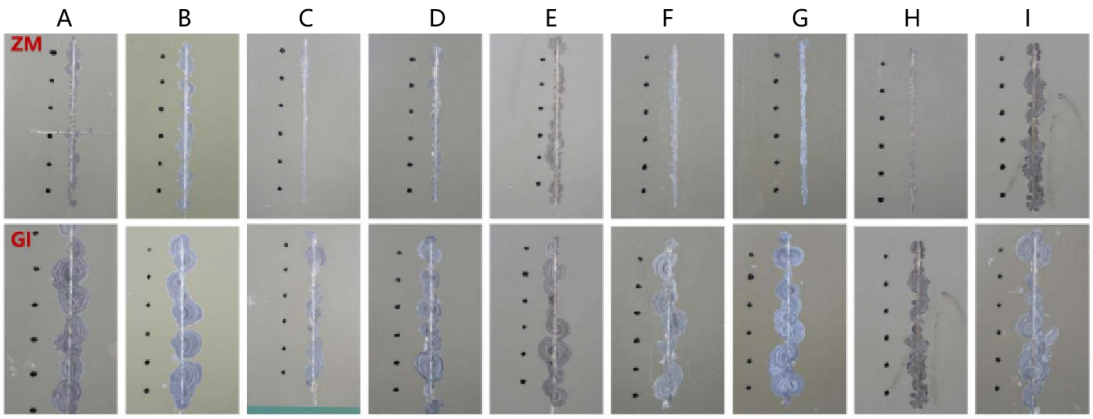

Fig.1 Corrosion results of ZM and GI electrophoretic plates using phosphating/film processes

Key words: Zn-Al-Mg, cyclic corrosion, pretreatment, etching width.

Multi-objective optimization of D-amino acids based corrosion inhibitor cocktails based on parallel Bayesian algorithm and Pareto frontier

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ABSTRACT

The corrosion of offshore oil-gas gathering and transportation pipelines has caused serious environmental risks and a global economic burden. Due to the coupling corrosion induced by multiple factors (acid, microorganisms, and so on) in offshore pipelines, corrosion inhibitor combinations may be promising for long-term corrosion protection in cases where single-function agents are ineffective. Endogenous D-amino acids (D-AA) coupled with quaternary ammonium salts (QAS) could provide new insight against corrosion with simultaneously synergistic adsorption behaviors and biofilm inhibition on the carbon steel surfaces. However, iterative trial-and-error experiments are not tenable to prioritize credible corrosion inhibitor combinations and achieve multiple performance optimizations, owing to the extremely large number of possible combinations. Herein, we provide a new avenue to accelerate the exploration of desirable corrosion inhibitor combinations via parallel Bayesian algorithm and Pareto frontier. Such an intelligent method could navigate the large search space and rapidly identify the ternary D-AA mixtures and single QAS combinations with the optimized adsorption and antibiofilm capabilities on the substrate. After evaluating ~10,000 combinations, 4 effective corrosion inhibitors were found and they significantly promoted the Pareto frontier formed by the original data set and remained environment friendly. Moreover, the Shapley Additive exPlanation (SHAP) tool was used to assist in the explanation of the synergistic mechanism of enhanced corrosion inhibition. This strategy holds great promise for rational design and multi-objective optimization of corrosion inhibitor combinations.

Numerical parameter identification for complex diffusion models using finite difference method

***Alexander Reichel*[1], Falk Naumann[1], Marco Rudolph[1], Marcel Mittag[1], Sandy Klengel[1]**

1) *Fraunhofer Institute for Microstructure of Materials and Systems IMWS, Halle (Saale), Germany*

In order to predict moisture related failure modes in microelectronic and power electronic devices (e.g. corrosion effects, formation of dinitrides) numerical approaches can be applied to determine important material parameters. Nevertheless, permeation parameter are mostly unknown and simulation approaches limited to the general diffusion equation of Fick's law. We present a numerical approach based on the finite difference method (FDM) in one and two dimensions, in order to extend the diffusion equation sufficiently by concentration dependency and adjustment of the boundary conditions. An unconditionally stable solving method for diffusion equations is realized by the Crank-Nicolson method in combination with second order discretization in space through the central differencing scheme and implemented into Python3. This enables to further refine the diffusion process by adding additional terms to the general diffusion equation, like saturation parameter of the material, convection velocity or temperature dependency. The simulation approach, expanded with a concentration-dependent diffusion coefficient allows the creation of sorption and desorption zones dependent or independent of the position inside the probe (Figure 1). The choice of boundary conditions provides the option of switching between Neumann and Dirichlet formalism to reproduce different experimental setups (Figure 2). Finally, the simulation results are compared to experimental data for a variety of different materials like silicone gel, insulation foils, polyurethane (PU) and polypropylene foils eg. used in foil capacitors.

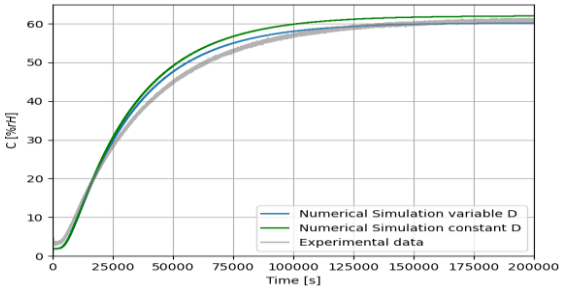

Figure 1: Comparison between constant and variable diffusion coefficient and experimental data

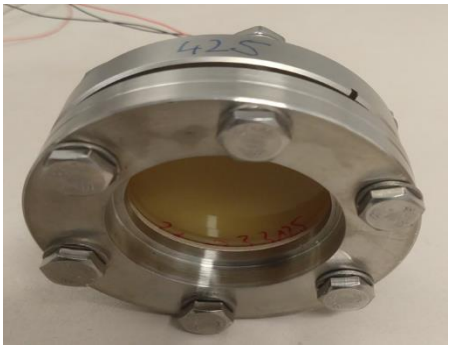

Figure 2: Experimental set-up for the diffusion measurements

Machine Learning-Based Statistical Modeling of Depassivation pH in Stainless Steels: Insights into Corrosion Mechanisms

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[2]Aperam Isbergues - Research Center, 62330 Isbergues, France.

[3]Formerly with Laboratoire Science et Ingénierie des Matériaux et Procédés (SIMAP), Grenoble INP, CNRS, 38402 Saint Martin d'Hères, France.

In this study, we introduce a novel approach to understanding the corrosion behavior of stainless steels (SS) through machine learning-based statistical modeling of the depassivation pH (pH_d). The research aimed to establish behavioral laws correlating the pH_d with the chemical composition of SS.

Using a comprehensive empirical database, we applied multiple polynomial regression techniques, with coefficients optimized via machine learning algorithms, to investigate the influence of alloying elements on pH_d. Particularly, our model elucidated the predominant role of chromium (Cr) and, to a lesser extent, molybdenum (Mo) in depassivation behavior. The study's findings are supported by Python codes, designed for ease of use in an Anaconda development environment, facilitating broader application and further research.

This work contributes to a multi-scale modeling strategy aimed at quantifying anodic dissolution kinetics and understanding the propagation mechanisms of anodic delamination. By providing a statistical perspective on the depassivation process, this research complements fundamental studies into the physicochemical complexities of SS localized corrosion, thereby enhancing predictive capabilities for industrial applications.

High-Temperature Oxidation of Stainless Steel, A Machine Learning Approach to Understanding the Role of alloying elements

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This study presents a comprehensive investigation into the high-temperature oxidation of stainless steels (SS), emphasizing the impact of alloying elements on oxidation kinetics. Through a multidisciplinary approach combining thermodynamic analysis, kinetic studies, and innovative machine learning (ML) techniques, we aim to elucidate the complex interactions governing the oxidation behavior of SS in high-temperature environments, highlighting the potential of ML in modeling such complex systems.

We employ an open-source tree classifier for linear regression algorithm to establish the relationship between alloy compositions, environmental conditions, and oxidation behaviors. This algorithm adeptly identifies linear correlations within the dataset, while the sure independence screening and sparsifying operator (SISSO) algorithm synthesizes these insights into a generalizable formula. This formula, equipped with finely tuned parameters, accurately predicts the oxidation behavior of ferritic SS across a spectrum of experimental conditions, offering a strategic scheme for designing oxidation-resistant alloys.

In summary, this study enriches the field of high-temperature oxidation of SS by harmonizing thermodynamic insights, metallurgical understanding, and kinetic data with cutting-edge ML techniques, providing valuable guidance for designing SS with enhanced resistance and advancing materials development for demanding applications.

Influence of solution treatment temperature on the pitting corrosion of a novel multiphase stainless steel

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Abstract

Pitting corrosion plays a vital role in the safe service of stainless steel. In this study, we performed an analysis of the pitting performance of a novel ferrite-austenite-martensite multiphase stainless steel, employing electrochemical techniques and material characterization methods.

The results indicated that as the solution treatment temperature increased from 1000℃ to 1150℃, the pitting corrosion potential of the multiphase stainless steel declined by 139 mV, the resistance of the passive film reduced by 37%, and the defect density in the passive film increased by 7%. SEM results revealed corrosion occurred in all phases. Thermodynamic analysis suggested that an increase in solution treatment temperature diminished the PREN value of all the phases, subsequently reducing their resistance to pitting corrosion.

Keywords

Multiphase stainless steel，Pitting corrosion

Designing high-strength and corrosion-resistant Mg-Y-Al alloys through precise control of the LPSO phase

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Generally, magnesium alloys always behave the trade-off between the mechanical properties, especially strength, and corrosion properties, due to the presence of the precipitates, which provides strong strengthening effect but deteriorates the corrosion resistant because of the micro-galvanic corrosion process. However, it has been proven that the addition of appropriate alloying elements, Y and Al, would promote the formation of compact surface film to improve the corrosion resistant of Mg alloys. This study focused on investigating the mechanical properties and corrosion behavior of Mg-Y-Al alloys with varying LPSO contents. Four Mg-Y-Al alloys with varied $V_f(LPSO)$ were designed guided by the CALPHAD-type calculations, aimed to investigate the effects of LPSO content on the mechanical properties and corrosion properties. The experimental results have shown that the yield stress of annealed Mg-Y-Al alloys increased as the increase of $V_f(LPSO)$. Besides, the corrosion rates of those alloys were lower than high-purity Mg (HP-Mg, 0.3 mm y^{-1}). The analysis revealed that the corrosion rate was less sensitive to changes in LPSO content due to the presence of a quasi-passivating corrosion film, effectively mitigating the micro-galvanic corrosion process. However, excessive LPSO phase content (~ 20 ± 2%) led to a substantial corrosion rate increase, attributed to the absence of a protective film and heightened susceptibility to pitting corrosion. These findings establish a practical range of LPSO content for forming a quasi-passivating corrosion film, offering crucial insights for designing high-strength and corrosion-resistant Mg alloys.

Comprehensive Evaluation of Bipolar Plate Materials for Alkaline Electrolysis: Literature Review, Electrochemical Analysis, and Interfacial Contact Resistance Development

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Abstract :

Alkaline electrolysis is a promising method for hydrogen (H_2) production, but the use of nickel-plated bipolar plates poses health risks [1]. A comprehensive literature review on bipolar plate materials and their selection criteria was conducted. It seems that stainless steel offers a potential alternative but their stability and performance need to be evaluated [2], [3]. This study investigates the corrosion behaviour of one ferritic and two austenitic stainless steels in an alkaline medium, comparing them with pure nickel, iron, and chromium. The electrochemical activity of all the addressed materials is thoroughly examined through cyclic voltammetry and chronoamperometry in aqueous 1M KOH at 23°C. Surface morphology and chemical composition of the studied materials are elucidated by Scanning Electron Microscopy (SEM) and X-ray Photoelectron Spectroscopy (XPS) after potentiostatic tests, respectively. Besides, additional chemical analysis (ICP-OES) is conducted in the tested solutions to identify leached chemical elements from the studied stainless steels. The results indicate that austenitic stainless steels with high nickel content exhibit ~~a~~ very promising corrosion performances. A method to measure the interfacial contact resistance, a performance criteria for bipolar plate, was also developed with a nickel mesh. The achieved results in this work provide a better understanding of the potential of stainless steel as a cost-effective alternative to nickel. Notwithstanding, further investigation is being carried out to address harsh alkaline conditions.

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Early-stage oxidation of single crystal Fe-18Cr-13Ni austenitic stainless steel exposed to water vapour

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Austenitic stainless steels are widely used for industrial and domestic purposes for their high strength, superior corrosion resistance due to a passive film, and non-magnetism. However, despite the presence of the passive layer, stainless steels are susceptible to localized corrosion such as pitting. Hence, understanding the structure and formation mechanism of the passive film can help in designing surfaces better resistant to pitting corrosion in future. Earlier studies performed using surface analysis techniques such as X-ray Photoelectron Spectroscopy (XPS) and Scanning Tunnelling Microscopy (STM) on clean alloy surfaces prepared in ultra-high vacuum (UHV) under oxygen exposure revealed that at room temperature, Cr oxidizes preferentially compared to Fe or Ni and the final oxide film had an inner layer markedly enriched in Cr however with Fe-rich weak sites.

While the alloy-oxygen surface reaction has been largely understood, the exposure to water vapour which can produce a different passive film is relatively unstudied. In this work, the adsorption of water vapour, subsequent reaction kinetics, passive film structure and chemistry were analysed using in situ XPS at room temperature. A single crystal (100)-oriented Fe-18Cr-13Ni was used as the sample. Subsequently water vapour was injected slowly into the system up to a maximum of 20 000 L (1 L = 1.33 $\times 10^{-6}$ mbar.s) and the evolution of the O1s XPS spectra was recorded simultaneously. Water vapour in contact with certain alloy surfaces in UHV conditions undergo splitting to form hydroxide ions and oxide ions. We have observed that on this alloy surface, with Cr and N co-segregated at the top surface, water vapour splitting to form oxide ions is preferred almost three times more than the hydroxide formation. A much slower reaction rate was observed with a larger exposure of water vapour (2900L) required to initiate the oxidation of Cr than with pure oxygen. However, Fe and Ni remained unreacted at growth saturation. The passive layer is then comprised of Cr oxides only, and thinner than that formed in oxygen.

Modelling of Zn and Mg Corrosion from the First Principles

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First principles calculations can be a useful tool in predicting the corrosion behaviour of metals. We combine the efficiency of Gaussian basis sets with range-separated hybrids to enable high-quality modelling of thermodynamics using Density Functional Theory. This approach allowed for the first time to plot accurate Pourbaix diagrams for Zn and Mg systems without the use of *ad hoc* corrections.

Why Accurate and Efficient Simulations Matter

A major advantage of simulations is prediction the properties of a system without the need for long-running experiments. Most commonly today Density Functional Theory (DFT) is used, relying solely on the electron density to describe the properties of the system. DFT can offer well-scaling and accurate simulations. A popular approach for implementing DFT uses plane waves and the generalized gradient approximation (GGA). Plane waves can describe the valence electrons to the theoretical limit but are computationally demanding. GGAs, while efficient, have been shown to underestimate binding interactions[1] and formation energies[2], necessitating corrections to the Gibbs free energy of the reaction. Even with the corrections applied, the calculated Pourbaix diagrams can differ significantly from the experiment. Additionally, corrections do not exist for the yet unexplored systems, preventing collaboration between theoretical and experimental researchers.

In this work we choose to use Gaussian basis sets for their lower computational cost without the loss of accuracy The switch enabled us to run range-separated hybrid functionals, which combine Kohn – Sham and Fock exchanges. This combination enables substantial improvements in the description of the materials involved in corrosion reaction and gives accurate Gibbs free energies at standard conditions. Consequently, prediction of corrosion via high-quality Pourbaix diagrams becomes possible. This method is universal in its applicability and can enable the exploration of systems which are hard to describe via experiment only, enabling to link the theory and the experiment in a reliable way.

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Development of a generic intergranular oxidation model for Fe-Cr-Ni alloys in pressurized water reactors

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Intergranular Stress Corrosion Cracking (IGSCC) is a major concern in Nuclear Power Plants (NPPs). Several components of Pressurized Water Reactors (PWRs) manufactured in nickel alloy 600 started to suffer IGSCC more than 30 years ago[1]. More recently, auxiliary lines made in austenitic stainless steel 316L experienced IGSCC. Therefore, there is a need in better understanding intergranular oxidation, which is a prerequisite to IGSCC.

Since 2015, EDF has developed a phenomenological model to predict the position of intergranular oxidation front as a function of time, temperature, electrochemical potential and percentage of chromium[2]. Parameters of the model have to be calibrated for each type of material.

At the same time, Chimie ParisTech has developed a physical oxidation model known as MSL[3]. Based on McDonald's point defect model[4], it describes the growth of uniform oxidation based on the transport of charged species.

The aim of this study is to engage the development of a generic model predicting intergranular oxidation and relying on physical mechanisms by coupling the MSL model with the chemical evolution of grain boundaries experiencing oxidation.

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Impact of segregation behavior on corrosion resistance in Ni-based superalloys

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Nickel-based superalloys are widely used in industry for aerospace or oil and gas applications due to their high strength and corrosion resistance properties that they retain even at elevated temperatures. The exceptional high-temperature strength characteristics are due to the dispersion of intermetallic phases, such as γ'' (Ni_3Nb), within the γ (Ni) Matrix. On the other hand, corrosion resistance is attributed to the presence of Cr, Nb, and Mo as solid solution within the matrix. While the interplay between the matrix, the intermetallic phases, and the dispersed solid solution elements may influence the alloys' properties, it remains largely unexplored due to the complexity of the multicomponent nature of these systems. In this study, we use density functional theory calculations to systematically study the segregation behavior of the alloying elements to the surface of the matrix and interfaces between the matrix and the Ni_3Nb intermetallic phase. Combining these calculations with a thermodynamic model we construct defect phase diagrams and discuss the effect of the segregation on the corrosion resistance of the Ni-based superalloys.

What if you could hear the stray currents?

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Stray currents created by railways can highly increase corrosion speed of nearly buried pipelines if it's not correctly handled.

An analysis must be conducted, xy graphs shall be edited with pipe potential in function of railways potential evolution.

We must ensure that the pipe potential is stabilized. To do so we must work on balancing of drainage which consists in having pipe potential stabilized. It can be made using resistors or regulators.

The required skill to perform this task is a level 4 in Cathodic Protection according to ISO 15257. However, the international norm allows those in level 3 to acquire this skill through corporate training and assessment.

We have developed a five days' training course through which learners are introduced to the origins, analysis, and treatment of stray currents. To ensure understanding and memorization during our trainings we work on offering a great learning experience including emotions and our 5 senses. In this training, we developed a model producing interferences according to the style of music it "hears". For instance, if classical music is playing, the stray current is at an acceptable level and the pipe doesn't need to be treated. However, if heavy metal is playing, then the stray current exceeds the acceptance limit, and the pipe must be treated. This helps our trainees understand the link between the intensity of the stray current, the potential impacts on the pipe, and the required actions.

We work on each of our training to ensure our trainees go back to their company ready to master the targeted skills. Our grid steel pipe trainings take place near Nantes on an exceptional site with 900 meters grid steel pipe allowing practice in real-world setup. Our trainers are experienced in their field, level 3 and 4 in cathodic protection, and possess excellent teaching skills.

Environmental factors impact investigation on corrosion protection of steel monopiles by organic coatings under cathodic protection

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Abstract

Offshore wind power is under strategic growth, with fast expanding larger wind turbine deployments, in shallow to deep waters, due to better wind conditions and environmental concerns. Steel monopiles, the primary choice for fixed bottom foundations, face severe corrosion issues, due to the harsh corrosive offshore conditions, demanding effective corrosion mitigation strategies. Understanding the complex interplay between cathodic protection and coatings performance, will facilitate the optimization of corrosion mitigation strategies for offshore monopiles, ensuring their structural integrity and enhanced service life.

This work focuses on the systematic investigation of the environmental factors affecting Impressed Current Cathodic Protection (ICCP) effectiveness, the coatings performance and degradation, as well as the understanding of the interactions between the ICCP and the coating system, for enhanced corrosion mitigation of steel monopiles. A lab pilot scale experimental setup is utilized, simulating real field conditions of a conventional monopile, for a more comprehensive perception of the interactions between ICCP potential levels and coating systems, allowing for an optimized corrosion mitigation strategy for steel monopiles.

Potentiostatic measurements were performed to control and assess the ICCP parameters and monitor the cathodic protection behavior. The corrosion rate, the coatings protective properties and the ICCP efficiency were evaluated with Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR). The coatings surface morphology and degradation extent were characterized by Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX). The chemical changes in coatings were identified with Fourier-Transform Infrared Spectroscopy (FT-IR). Continuous environmental conditions monitoring was implemented for understanding ICCP and coating system's performance, thereby providing guidance for refining monopile corrosion protection strategies.

Regulating corrosion resistance of Mg alloys via promoting precipitation with trace Zr alloying

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Poor corrosion property has been a bottleneck problem during the application of Mg alloys. This work proposes a new way to improve the corrosion resistance of MgNd alloy by micro-alloying Zr, which promotes the precipitation process to rapidly form a protective corrosion layer. The corrosion rate decreases by three orders of magnitude from 32.69 mL/cm2/day to 0.072 mL/cm2/day. The results show Zr tends to form nano-scale oxide clusters on Mg surface, acting as pre-precipitation sites to accelerate the precipitation and facilitate the formation of dense and compact corrosion layer.

A simple method to characterize the corrosion film compactness by nanoindentation

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The corrosion film compactness of metals determines the corrosion resistance, however, it is difficult to characterize the film compactness quantitatively via convention methods, such as SEM, TEM and electrochemical test. Micromechanical properties directly reflect the film compactness. Nanoindentation can expertly characterize micromechanical properties of the corrosion film which immunes to the thickness limitation and the substrate effect. Therefore, by using nanoindentation to measure the hardness and the modulus of the corrosion film in different concentrations of Cl^- solutions, the various of film compactness can be illustrated obviously.

Testing Repair Coatings for Corrosion protection applications

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This work focuses on qualification of dedicated repair coatings (RC) by recreating field-like application conditions under laboratory conditions and testing their corrosion protection capabilities. A standardized damage is applied to a primary coating on samples to expose its carbon steel substrate. Accelerated corrosion by salt-spraying (ISO 9227) and acid pickling are applied to the samples. RCs are applied after derusting (St 3). The patched systems are subjected to cyclic weathering (ISO 11997), salt spray and immersion tests to assess their corrosion protection capabilities.

Corrosion protection overhauling in waterways engineering

Long-term protection of steel works in humid and aqueous environments against corrosion is a daunting task for most coating systems. Dedicated repair coatings face even harder challenges concerning application conditions and adhesion in addition to their corrosion protection task.

The application conditions and substrate preparations for primary corrosion protective coatings can be optimized by for example enclosing the construction site, cleaning and sandblasting to Sa 2½, selection of specialized contractors and equipment. This does not apply to repair coatings.

Prior assessment of the corrosion protection in underwater areas is difficult. Therefore, damages are often only detected after drainage. The repair of corrosion protections should last as long as possible, to minimize construction costs. Additionally, the overhauling of the corrosion protection should be swift, to reduce downtimes on waterway infrastructure, especially if it is non-redundant. This often results in a situation where repair works must be handled by on site personal, in adverse weather and without enclosure or proper surface preparation. RCs designed to accommodate such circumstances are attractive options in these situations.

Resulting challenges for RCs may include hand derusted substrates (St 3 or St 2), chalking of the prior coating, high or low temperatures, condensation and contaminants such as salt on the surface. Recreating these conditions in controlled environments is thus of high interest for qualification purposes.

Development of highly corrosion-resistant Mg-Al-Y extruded alloy via precipitating dispersed $Mg_{17}Al_{12}$ phase

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Mg alloys are susceptible to corrosion in service environments due to their high chemical activity, low standard electrode potential (−2.37V/SHE), and poor protective properties of the surface film, which has become the main reason limiting their large-scale application. Alloying and microstructure regulation are the main means to improve the corrosion resistance of Mg alloys. In this work, we developed a highly corrosion-resistant AW90 extruded alloy (Mg-9Al-0.2Y wt.%) with dispersed $Mg_{17}Al_{12}$ phase via Y microalloying and solution-aging treatment. The aged AW90 alloy has an extremely low corrosion rate of 0.14 mm/y (weight loss), which is expected to become a corrosion-resistant magnesium alloy for large-scale application. In this study, the corrosion behavior of the as-extruded, T4 and T6 AW90 alloys are investigated in detail. The corrosion mechanisms of the three alloys are discussed, especially the high corrosion resistance mechanism of T6 alloy. The solution-treated AW90 alloy exhibited the most severe localized corrosion, which can be attributed to the strong micro-galvanic acceleration effects of small amounts of Al_8Mn_4Y/Al_2Y phase. More importantly, it is found that the finely dispersed $Mg_{17}Al_{12}$ phase favors the uniform corrosion of T6 alloy and the formation of a uniform and dense corrosion product film in the initial stage of immersion, resulting in the strong quasi-passive behavior of T6 alloy. The high corrosion resistance of the T6 AW90 alloy is attributed to the formation of the dense Mg-Al layered double hydroxide film, which has stronger resistance to chloride ions.

Corrosion Protection Coatings for Offshore Wind Structures: Real Marine Exposure vs accelerated laboratory tests

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This research addresses the critical issue of corrosion protection for metallic structures in the offshore wind energy sector, focusing specifically on coatings for structures in marine environments such as monopiles and jackets. In this study, we evaluated diverse coating systems for application in atmospheric, splash, and submerged zones and compared their performance under accelerated laboratory aging with real field exposure over one year.

The coatings under investigation were aged using traditional accelerated cyclic corrosion tests according to ISO 12944-9/Norsok M-501 and were also exposed for one year at an offshore testing facility. An extensive characterization was performed after both laboratory aging and real marine exposure to establish a correlation between the two aging methods and the actual degradation of the coatings. Our results showed that some laboratory tests were less aggressive than real offshore conditions, emphasizing the necessity of field exposure data for accurate corrosion assessment. Additionally, the aging rate of the coatings varied significantly with coating type, and the correlation between the two methods was not always straightforward.

Furthermore, in order to shed light on an optimized coating performance, a comparative analysis was carried out as follows: 1)Zinc-rich Epoxy primer vs. Epoxy glass flake vs High Build Epoxy; 2)Coatings which impart galvanic protection: Metallised vs Zinc-rich Epoxy vs film galvanising systems; 3)Different types of metallised coatings: topcoated TSZA (Thermal Spary Zinc-Aluminium), vs topcoated TSA (Thermal Spray Aluminium)

Our findings contribute to a better understanding of the limitations and potential of accelerated corrosion tests, providing valuable insights for improving the testing, qualification, and selection of corrosion protection coatings for offshore structures at the industrial level.

Numerical modeling of corrosion fatigue crack growth in medium-strength steel Compact Tension specimens under offshore conditions

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Abstract

A simplified, realistic corrosion fatigue model is proposed to predict the corrosion fatigue crack growth rate (CFCGR) in S355 Compact Tension (CT) specimens. This model assumes that the total crack propagation in each cycle, Δa_{cf}, is the summation of both, inert crack propagation, Δa_f, and corrosion crack propagation, Δa_c. To this end, the concentration of solution species, especially H^+, is calculated by solving the Walton equation, considering governing electrochemical reactions, diffusion, and mass transfer terms due to fluid flow inside of the crack. That latter is obtained through the computational fluid dynamics analysis of the fluid inside the crack, which is subjected to the pumping effect of the cyclic displacement of the crack faces. It is worth mentioning that the pumping effect is a function of the loading ratio (R) and the crack geometry. Once the pH value at the crack tip is determined, Δa_c can be computed using the empirical loss rates obtained from material dissolution tests conducted on S355 samples in artificial seawater at different pH levels. The proposed model can capture the in-situ corrosion fatigue crack growth in medium-strength steels with free external potential at different temperatures and loading parameters.

Keywords: Corrosion fatigue, Loading parameters, Electrochemistry, Crack geometry, Temperature.

Electroluminescence detection of electron transfer between metal and microorganism

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This work was focused on possible threat of EMIC on canister for deep geological repository of spent nuclear fuel. Large screening exposures using large scale of different media were carried out in order to predict most aggressive anaerobic strains in Czech bentonite BCV. Special black cell for luminescence detection was constructed. Zinc based coupons were treated to achieve thin and continuous semiconductive ZnO layer. Those coupons were exposed in synthetic bentonite pore solution (abiotic/biotic). The results showed the electroluminescence is promising complementary method for detecting EMIC suspicious strains.

Effects of N-heterocyclic carbene-enhanced coatings on microbial corrosion of mild steel

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Nitrate-reducing bacteria can play a significant role in microbial-influenced corrosion (MIC) but are significantly less studied than the better-known sulfate-reducing bacteria. In this study, we aim to investigate the effects of nitrate reduction on corrosion using *Escherichia coli*, a model bacterium that reduces nitrate under sub-oxic conditions. In addition, this research examines the efficacy of metals enhanced with N-heterocyclic carbenes (NHC) in protecting against MIC. In recent years, NHCs have gained recognition as attractive ligands for metal catalysis due to their ability to form stable bonds with transition metals. Consequently, newly synthesized NHCs demonstrate the potential to increase adhesion between corrosion-resistant coatings, such as epoxy, and the metal surface. Uncoated, epoxy-coated, and epoxy-NHC-coated mild steel coupons were exposed to *E. coli* ATCC 25922 grown in media with and without nitrate. The level of corrosion was evaluated through dissolved iron concentrations in the media, mass loss and electrochemical measurements. Changes in the biofilm and the metal surface were examined using scanning electron microscopy with energy-dispersive X-ray spectroscopy and optical microscopy. The presence of nitrates significantly increased the mass loss of mild steel in uncoated samples. In the absence of nitrate, epoxy and epoxy-NHC-coated coupons exposed to *E. coli* had more oxidized surfaces and increased visual corrosion compared to the sterile control. This research will help establish the role of nitrate reducers in MIC, the effectiveness of NHC as a coating enhancer, and provide a baseline for testing against more severe corrosion-causing bacteria.

Comprehensive characterization of microbiologically influenced corrosion by Acid Producing Bacteria on carbon steel

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Microbial corrosion has become a major concern across different industries that needs to be investigated and properly addressed. In this context, the current study examines the impact of Acid Producing Bacteria (APB), specifically *Photobacterium* A1, on the degradation of carbon steel in marine environments. The research is centered on understanding how APB-driven processes contribute to the deterioration of commonly used carbon steel structures in marine contexts. Nuclear Magnetic Resonance was performed to evaluate the organic acids produced by *Photobacterium* A1. Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy (SEM/EDS) and Confocal Laser Scanning Microscopy tests were utilized to study the role of localized acidic microenvironments beneath biofilms in expediting metal degradation. Mass Loss tests were conducted to compare uniform corrosion rates in both biotic and abiotic samples, thereby quantifying the metal loss attributable to MIC. The study includes electrochemical investigations via Linear Polarization Resistance and Electrochemical Impedance Spectroscopy. These methods are employed to analyze the long-term kinetics of corrosion during each phase of the biofilm formation. This approach offers detailed understanding of the fundamental mechanisms involved in iron dissolution and hydrogen evolution, which are the key anodic and cathodic reactions in the corrosion process. The findings highlight the corrosive potency of APB-secreted volatile fatty acids and their contribution to iron dissolution, underscoring the need for effective anti-corrosion strategies in marine applications.

Microbiologically influenced corrosion (MIC) in an industrial fire protection system

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Corrosion in fire protection systems (FPS) is one of the major issues for maintenance and operation and the presence of corrosion products and damages can have impact on the operation in case of a fire. Corrosion in FPS can be induced amongst others by corrosive water quality, the wrong choice of material, supply of oxygenated water, stagnant water or also due to microbiologically influenced corrosion (MIC). MIC is a rapid form of corrosion initiated or accelerated by microorganisms. Unlike other problems in FPS, MIC is still difficult to predict and finding the best treatment approach against MIC is not easily determined. Proper MIC diagnosis is a process of collecting appropriate scientific and practical knowledge from different expertise areas requiring a case-by-case approach. This paper describes the investigation of MIC failure case in an industrial fire protection system following the multiple lines of evidence principle. Water samples were taken and parts of the pipelines were exchanged from the system and further analyzed in the laboratory. After visual inspection, swab samples were taken for microbial analyses (DNA- and growth-based approach), cross sections were done, and samples were analyzed by SEM-EDX. Water samples were analyzed by ion chromatography (IC) and inductively coupled plasma-mass-spectrometry (ICP-MS). Physical-chemical analysis of the water samples showed high conductivity and high values for S and Cl. The interior of the pipes suffer from uniform and localized corrosion with the presence of tubercles. SEM-EDS showed high values for chloride (Cl) and sulfur (S) in the corrosion products and cross sections showed formation of different layers. S and Cl were accumulated on the metal surface covered by an oxide layer. Microbial analyses showed presence of different MIC relevant groups of microorganisms in water and corrosion product samples. Especially, the numbers of sulfate-reducing bacteria (SRB) were higher in corrosion product sample as compared to the water samples. The results showed that next to oxygen corrosion and the presence of chloride, MIC plays a role in this failure case.

Can microbial nanowires be relevant more than mobile shuttles in promoting microbial corrosion?

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Microorganisms can influence corrosion of metal alloys by creating a biofilm that change the electrochemical conditions at the metal-solution interface, usually to achieve nutrients and a satisfactory environment for the microbial community.

The respiration of microorganisms consists in a cascade of redox reactions where electrons are delivered to a final electron acceptor (oxygen, nitrate, sulphate, etc.) by protein electron-carriers. Corrosion phenomenon occurs at the metal-solution interface, driven by the electrical performance of this specific space region.

A network of extracellular polysaccarydes (EPS) constitutes the structural component of the biofilm, which can become more than 100 μm thick. Extracellular Electron Transfer (EET) inside the biofilm can occur through both the structural network of EPS, and bacterial membranes (dielectric components), and the ionic conductive water constituting most of the biofilm weight (more than 95%), due to dissolved ions and enzymes in it.

The most popular possible models for EET in biofilm can be summarized as: a) by direct contact or by conductive cell extensions (pili) of living cells, b) through a conductive EPS network inside the biofilm, c) by utilizing electron-shuttles (extracellular or self-excreted small molecules such as phenazines, flavines, quinones, extracellular cytochromes hydrogenase etc.). The most recent studies point to the role of nanowires that might conduct electrons in long (microbial) distances (centimeters) [1]. Here the role of such filaments in corrosion is critically discussed and rather neglected. The use of electron shuttles more effectively is hypothesized to allow pools of accumulated microorganisms located away from the metal surface to actively contribute to the electrochemical process.

[1] D. Lovely, D. Walker. Front. Microbiol., 24 September 2019, Volume 10 - 2019 | https://doi.org/10.3389/fmicb.2019.02078

Hierarchical Surface Texturing Modifies the Contact-Killing Effect of Bacteria Pseudomonas sp. On Stainless Steel

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Bacterial attachment to material surfaces can lead to the development of biofilms that cause severe economic and health problems. Several studies have shown that bacterial settlement can be controlled to a certain degree using patterned surfaces featuring repeating topographical elements ranging from nanometers to micrometers. Yet, understanding the underlying mechanisms of attachment, settlement, colonization, and contact-killing is still limited[1]. Surface texturing is a possible alternative for controlling the interaction between bacteria and surfaces, affecting initial adhesion and settlement of first colonizers of biofilm formation and later biofouling and biocorrosion. Recent studies have pointed out the possibility of controlling the bacteria adhesion and settlement on surfaces by combining micro and nano-feature patterns[2,3]. Some studies have shown that bacterial adhesion can be controlled to a certain degree using patterned surfaces featuring repeating topographical elements of sizes ranging from nanometers to micrometers.

In this work, we show the effect of hierarchical surface patterns on the contact-killing effect of bacteria on stainless steel. The surface texturing was carried out using optical lithography and etching techniques. Physical and chemical surface properties were measured by atomic force microscopy (AFM), scanning electron microscopy (SEM), glow discharge optical spectroscopy (GDOES), X-ray photoelectron spectroscopy (XPS), and contact angle testing. These properties were correlated with the live/dead testing results using the biofilm-forming bacteria *Pseudomonas sp*. at different exposure times. Our results show that hierarchical surface texturing promotes changes in bacterial contact cell death, with more significant statistical cell death overtime on smaller-scale textured surfaces than on bigger-scale topography. Also, the results indicate that changes in chemical composition do not play a relevant role in the contact-killing effect of bacteria on stainless steel.

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Development of Anti-corrosion and Anti-biodeterioration Coating Materials in Water Distribution Systems

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Hong Kong has been one of the few places extensively applying seawater for flushing since the late 1950s. The use of such a sustainable resource continues to play an important role in the water management of Hong Kong. Every year, Hong Kong requires 970 million cubic meters of freshwater and 270 million cubic meters of seawater to meet the requirements of citizens and industries. Long distances and a specific geological environment increase the possibility of microbial contamination and growth, and the intricate composition of seawater further amplifies concerns about corrosion problems. Physical and microbial corrosions of metals not only remarkably increase the water treatment cost but also seriously threaten water quality and human health. Moreover, it can increase the surface roughness of water pipes and plants which may decrease the water transport efficiency, shorten infrastructure life, and increase the maintenance frequency of water distribution systems.

In this research, multiple antimicrobial polymers (MAP) were applied in epoxy-based materials to develop an environment-friendly and effective anti-corrosion and anti-biodeterioration coating to protect water pipes and plants. The novel coating could effectively prevent the adhesion of bacteria and exhibited excellent bactericidal activity. The result of the Tafel test indicated that MAP improved the corrosion inhibition efficiency of polymer epoxy and ceramic epoxy from 31.4% to 70.8% and from 73.1% to 80.0% respectively. On the other hand, a pilot-scale friction test rig was built to simulate the real service environment of the coating material. Compared to the uncoated water pipes, the coating material endows pipes with a smoother surface. It could obviously decrease the friction loss of pipes while enhancing water transportation efficiency. The application of the novel coating material would focus on safeguarding the water distribution system, while simultaneously improving its efficiency by decreasing cost, energy consumption, and greenhouse gas emissions associated with water supply.

Microbiologically Induced Corrosion: A Dual Approach for Industrial Insight

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Microbiologically induced corrosion (MIC) poses significant economic challenges in various industries, such as oil and gas, water utilities, and port facilities. Despite many decades of research, the mechanisms of MIC remain elusive. In fact, even the corrosion mechanisms under complex scenarios are not yet fully developed due to the large number of variables involved (e.g., metal and solution composition, and other environmental conditions). The contribution of microorganisms only adds to the already existing complexity. This project aims at developing some understanding of MIC using two approaches. At first, we will explore traditional and new theories on corrosion mechanisms, focusing on how they may be affected by microorganisms through chemical and biochemical interactions. These will be incorporated in mechanistic numerical models based on reactions (electrochemical, biochemical, chemical, precipitation/dissolution, etc.), ion transport (diffusion, migration) and electron transfer. In parallel, an experimental setup utilizing localized electrochemical impedance spectroscopy (LEIS) will be used to map corrosion parameters in time, under abiotic and biotic conditions (biofilm-influenced, with focus on sulphate reducing bacteria). The experimental data and the modelling will be combined into an MIC model that couples a biofilm development with electrochemical corrosion. Other advanced surface and microstructure characterization techniques (SEM, TEM, AFM, CLSM) will be used to capture the physical characteristics of the corroded surfaces and biofilms. The output of this project will provide more mechanistic understanding of the MIC processes. An eventual extension of this approach may help predict potential equipment failure and aiding in the mitigation of MIC in industrial systems.

Identification of the extreme conditions at the origin of the initiation and propagation of localized corrosion of a carbon steel in a cementitious material

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In the frame of the long-term disposal of High-Level Waste (HLW) in deep geological repository developed by Andra (National French Agency for Radioactive Waste Management), steel containers enclosing vitrified nuclear waste will be confined in horizontal tunnels lined with a carbon steel casing. In order to avoid active corrosion of this steel overpack in contact with the Callovo-Oxfordian claystone (COX), the gap between the claystone and the casing will be filled with a high pH cement grout aiming at maintaining the steel surface in a passive state. However, the pore water of the COX and the cement contain sulfides and chlorides which are both known for their negative impact on passivity. Then it is important to examine the conditions that could lead to depassivation to comfort the safety margins of this disposal part.

In this work, laboratory experiments are designed for simulating and monitoring the corrosion behavior of representative steel coupons in different cement grouts in aerated conditions with varying concentrations of chlorides and sulfides at 20°C and 50°C. For this purpose, the passivity is monitored using in situ OCP measurement. At the same time, EIS measurements are performed to assess the evolution of passivity through a Mott-Schottky analysis. This first approach being carried out with polished steel samples, the influence of a native oxide layer formed in atmospheric conditions is also studied.

Evaluating Scraping Requirement for Low-Velocity Gas Flowlines: An Effective Approach and Alternatives

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In mature gas reservoirs, production flowlines typically experience low flow velocities. Flowlines operated at low velocity are subjected to the risk of under deposit corrosion due to liquid settlement and solids deposition which also hinder the effectiveness of corrosion inhibitor. In such cases, cleaning scraping is required to counteract this adverse impact upon the confirmation of liquid settlement and/or solids deposition. Two objectives can be achieved by applying scraping: ensuring effective distribution of the corrosion inhibitor and removing settled liquid and/or deposited solids.

This paper discusses the challenges associated with scraping gas flowlines that were not originally designed with permanent scraping facilities. An engineering approach to determine the need for scraping is presented which considers computational fluid dynamic (CFD) analysis and flow assurance simulation. In addition, other useful data are also considered which includes inspection history, type of damage mechanisms, sampling analysis, and solids quantities and characteristics.

The paper also evaluates alternative scraping launching and receiving facilities (i.e. portable/temporary scraping facility and scraper ball valves) if scraping is deemed necessary. These alternatives are more cost effective and they address operational challenges in comparison to the conventional scraping facilities.

Influence of 15Cr martensitic stainless steel ferrite on mechanical properties

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With the rapid development of the petroleum industry, the service conditions of stainless steel for oil well pipes are becoming more and more demanding. Among them, 15Cr martensitic stainless steel has good mechanical properties, good corrosion resistance and low economic cost, which makes it widely used in oil fields. In this paper, by adjusting the composition of 15Cr martensitic stainless steel and introducing ferrite, the ferrite/martensitic heterostructure was formed. The material was heat treated at different temperatures to characterize its different structure components and mechanical properties. The results are as follows: the ferrite has high Cr content and low Ni content; The hardness of martensite is higher than that of ferrite. In addition, with the increase of heat treatment temperature, the ferrite content increases, and the morphology changes from long strip to short strip and block, and the strength decreases and the elongation increases.

Localised corrosion of steel pipeline associated with weldments in CO_2 containing environment

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ABSTRACT

In this work the corrosion behaviours and metallurgical characterization studies of the different weld regions such as parent metal (PM), heat affected zone (HAZ) and weld metal (WM) of X70 grade pipeline steel is reported. Electrochemical techniques such as corrosion potential monitoring, polarisation resistance technique and galvanic current measurements were employed to evaluate the corrosion behavior of the testing materials. Optical microscopy was used for metallurgical characterization studies. Galvanic current measurements for the coupled weld regions under static conditions showed that selective weld corrosion attack were minimised either in the WM or the HAZ relative to the adjacent region of the PM

Key words: Welded steel X70, Weld attack, Galvanic tests, CO_2 corrosion.

Analyzing Residual Corrosion Inhibitor Concentration in Solution by FTIR

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Abstract

The utilization of corrosion inhibitors (CIs) in oil fields stands as a practical and efficient strategy for corrosion control. The selection of a specific inhibitor and its dosage depend on CI compatibility with other chemicals, brine composition, temperature, pressure, foaming tendency, etc. The inhibition effectiveness needs to be ensured by measuring the residual corrosion inhibitor (RCI) concentration in production fluids which can be done using various analytical techniques. In the context of offshore installations, it becomes crucial that these techniques permit the use of portable equipment and do not require intricate sample preparation. Fourier-transform infrared spectroscopy (FTIR) is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid, or gas. The resulting spectrum, formed by bands corresponding to different functional groups, is a fingerprint of the sample. This technique is non-destructive, rapid, and precise for molecular identification and it has the potential for portability. This study focuses on investigating the applicability of FTIR for determining RCI concentrations in solution, evaluating the pure inhibitor compound Benzalkonium chloride (alkyldimethylbenzylammonium chloride). The advantages and limitations of FTIR technique for RCI quantification in solution are discussed. In addition, the co-influence of contaminants was investigated. By addressing these aspects, the study aims to contribute with insights into the feasibility and reliability of FTIR as a tool for monitoring residual corrosion inhibitor concentrations in oil field applications.

Quantifying Residual Corrosion Inhibitor Concentration in Solution by UV-Vis Spectroscopy Using Different Indicators

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Abstract

The effective control of corrosion in metallic components and pipelines within oil fields relies significantly on the use of corrosion inhibitors. Establishing the appropriate dosage of the corrosion inhibitor before implementation in operations and continually monitoring the system for dose adjustments are important steps in preventing unforeseen shutdowns and reducing maintenance costs. However, there is currently no standardized method for detecting and monitoring the optimal dosage of corrosion inhibitors in operation. A way to assess the corrosion inhibition effectiveness is by measuring the residual corrosion inhibitor (RCI) concentration in production fluids. There are many techniques for detecting and monitoring the residual content of inhibitors, some offer high resolution, sensitivity, and reproducibility but lack portability. Moreover, certain techniques require complex sample preparation and are time-consuming being not suitable for offshore application. UV-Vis spectroscopy is a technique found in laboratory protocols to quantify RCI in oilfield brines. The use of this technique to detect RCI is based mainly on dye transfer methods, where complexes are formed between inhibitors and indicators, and subsequent extraction into an organic phase, typically chloroform, enables quantitative analysis. In this study, the complexation behavior using three indicators (disulfine blue, methyl orange and bromophenol blue) is investigated. Additionally, the influence of many parameters was considered, such as dye concentration, pH, and inhibitor solution concentration, to find the best conditions for RCI measurement. The pure inhibitor compound used in the tests was a quaternary salt named Benzalkonium chloride-BAK (alkyldimethylbenzylammonium chloride).

Surface analysis of flexible pipeline components – digitalization of corroded wire segments removed from dissection.

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Currently, Brazil has 64 platforms operating for more than 25 years in a CO_2 environment, whose subsystem or component requires the replacement of such equipment with a similar one or its decommissioning. In this context, surface analysis and digitalization of steel components removed from different layers of a flexible pipeline, after about 30 years in operation, was carried out. During the dissection process of this riser, segments of pressure, and tensile armours, internal and external, were sectioned and sent to laboratory for investigation of relevant damage mechanisms and general surface conditions. The surface digitalization methodology was inittially based on macroscopic - 3D scanning – and, after that microscopic analyses was performed, using scanning electron microscopy, confocal laser scanning microscopy, smartzoom optical digital microscopy. The macro 3D scanning method was used to generate a digital three-dimensional image of the components. Therefore, it was possible to select some regions with/without the presence of surface damage for microscopic analysis. The digital results will support the better understanding of the surface morphology of the wires using different parameters. This pilot study will be used to assess the general conditions of structural components after its life cycle. These information can be used to estimate service life of the pressure and tensile armours layers of risers, among others, based on the comparison with a simulation model (virtual object) designed, based on the equipment original specifications.

Role of Microstructure and Heat Treatment in Corrosion, Cracking and Material integrity

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During failure analysis of the operational failures in the equipment of an upstream oil & gas industry, it was observed that there is some correlation between the microstructure/heat treatment and the failure mechanism which led to premature failures of these components. So in this technical paper, few case studies are discussed regarding the premature failures due to improper heat treatment and microstructure.

In the first case, an onshore well of a Coal Bed Methane field, PCP was installed and just after 20 days of working, rotor of the PCP pump snapped. While pullout, it was found that Rotor was parted from top and remaining part of rotor stuck in the stator. The metallographic studies revealed ferrite pearlite microstructure with high pearlite content (62.5%). The presence of cracks propagating through pearlite phase and intergranular spaces are a signature of Hydrogen Induced Cracking, so due to the presence of significant amount of pearlite phases, which are hard and brittle, the cracks propagated through them under existing torsional fatigue load and finally the material got fractured in brittle mode.

In second case it is observed that the Water pump-A motor of utility water plant was drawing high current. The water pump was pulled out and dismantled for inspection and found that the pump shaft experienced sever corrosion damage and material washed out at several portion along its length. Metallography studies revealed that the specimen has microstructure of austenite-ferrite phase typical of a super duplex stainless steel and also exhibited presence of undesirable sigma phases, So one of the major reasons of the failure of the pump is primarily due to the presence of array of sigma phase in the microstructure due to improper heat treatment, which in turn made the component very brittle and less corrosion resistant.

In the third case Well Services Section of an Onshore Asset, during work over observed that Sucker Rod of one of the onshore oil well field was broken from upset taper head. The Sucker rod was pulled out and it was found that Sucker rod was broken. The metallographic analyses of the failed rod sample revealed martensite with retained austenite microstructure which is not acceptable for this type of material and Stringers in the metal matrix have been observed as stringers are weakest site where a crack can initiate and it lead to premature failure of the sucker rod.The details of tests and suitable remedial measures are discussed in detail in the paper.

Keywords: *Rotor, Hydrogen Induced Cracking, Sigma phase, Retained Austenite, Stringers.*

Corrosion Investigation of TEG System Equipment at Gas & Oil Separation Plant

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This paper will summaries the root cause analysis, findings, observations and main recommendations of an internal corrosion findings reported in seven equipment of the Tri-Ethyne Glycol (TEG) system in an oil & gas separation plant.

TEG dehydration unit is designed to dehydrate the gas stream to ensure that the water content of the dry gas leaving the facilities does not exceed 7 Ibs/MMSCF. Lean(dry) TEG in the contactor is used to absorb the moisture, the rich (wet) TEG is sent to the regeneration package where the absorbed moisture is removed to produce lean TEG solution with purity above 98 wt%.

In the regeneration backage the rich TEG fed to the TEG Reboiler, were it will be heated by fired fuel gas to 395 F maximum as per the vendor design specification to achieve TEG concentration of 98.5%. As per the design specification the regenerator TEG temperature shall not be greater than 395 F. However, temperature was found to be operated above 395 (occasionally) reaching up to 407 F which is above the degradation temperature (404 F). Moreover, degraded TEG forums acidic corrosive compounds. In addition, Amine injection pumps, which are used to neutralize the pH, were not frequently operated with an observed low pH of lean and rich TEG.

Based on the main findings, observations and considering the available routine sampling tests the most probable root cause for the internal corrosion findings in the TEG system is operating the TEG out of process integrity operating windows (IOW), therefore, it was recommended to revise the IOW's and ensure to operate the TEG system within the updated IOW's.

Inspecting and Improving the Integrity of High Restriction Pipelines

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Pipeline In-line inspection (ILI) is a reliable and well-established technique to assess the integrity of pipelines. ILI requires an initial assessment of the pipeline condition and internal minimum passage before any ILI tool can be launched in a pipeline to ensure that the pipeline passage is suitable for the ILI. However, there are several factors and challenges that can prevent ILI in piggable and difficult to pig pipelines, such as low flow, multi-diameter pipelines, tight bends, and pipelines with unknown restriction. This paper will go through a field experience, technical evaluation, and a success story of utilizing a Foam-based Eddy Current (EC) ILI tool to inspect a piggable pipeline where the ILI was not possible by conventional tools due to a major and unknown restriction in the internals of the pipeline. The tool successful deployment will allow for an accurate and reliable inspection and assessment of high restriction pipelines safely while eliminating the risk of stuck ILI tools. This opens a new window and opportunity for the revalidation and inspection of high restriction pipelines to maintain their integrity, reduce down time, and failures.

Impact of Protective Gas Levels and Surface Roughness on Pitting Corrosion of AISI 316L Welds: Simulation and Experimental Correlation

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This study evaluates how varying oxygen levels in protective gas influence the pitting corrosion resistance of AISI 316L stainless steel pipelines welded using arc welding. Two welding techniques: Gas Tungsten Arc Welding (GTAW) and GTAW combined with Flux Cored Arc Welding, commonly used in industry for pipe welding, were used. Oxygen concentrations in the range 50 to 5000 ppm, and two different surface roughness levels were examined. Using Scanning Electron Microscopy (SEM), the thickness of the oxide layer formed on the steel was measured. Finite Element Method (FEM) and finite volume method (FVM) were applied to analyze temperature distributions and gas distribution within the oxide layer and detailed predictions on the formation of the oxide layer using FactSage thermodynamic software. To study oxidation behavior, Thermogravimetric Analysis (TGA) was performed at heating rates from 2 to 25 °C/min, to follow changes in the oxide layer with temperature and calculate the activation energy of the steel. Corrosion tests in an acidic-salty environment according to ASTM G5-13 standard were conducted and Electrochemical Impedance Spectroscopy (EIS) was employed to assess the protective quality of the oxide layer.

The results showed that oxide formation began at 800 °C and significantly increased after 1200 °C. The oxide layer thickness, predicted using simulation and TGA results, was validated by electron microscopy examination. An increase in oxide layer thickness was observed with higher oxygen content, and a porous structure was noted when 5000 ppm oxygen was used in the backing gas. Pitting corrosion resistance increased with oxygen content up to 500 ppm but decreased at 5000 ppm. Additionally, smoother surfaces were more sensitive to pitting corrosion. Our findings demonstrate the significant effects of oxygen content in the protective gas and the surface roughness on the corrosion performance of AISI 316L stainless steel.

Investigating the Corrosion Products in Heat Exchangers of an Anomia Petrochemical Plant – A Case Study

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Objectives

The corrosion products in a heat exchanger operated by one of the petrochemical complexes in the Iranian region of Asalouyeh were investigated to determine the nature of corrosion products and provide methods for removal of the products and improving the heat exchange rate of the exchanger.

Results

The corrosion products were removed during a process overhaul. Characterization was carried out using XRF and XRD studies. To determine the removal method for the products, various solvents including concentrated and diluted HNO_3, HNO_3 – 20% HCl, 10% H_2SO_4, concentrated H_3PO_4, concentrated HCl, H_2SO_4 – 10% H_2O_2, and KCN solutions were texted at the limit of the system's operating temperature of 50℃. According to the XRF results, the corrosion products contained 94.468% Fe_2O_3 and 2.57% Cr with small amounts of other elements. The XRD pattern obtained from the corrosion products showed it to contain mostly γ-Fe_2O_3 phase with FCC structure. Based on these results, the corrosion products were determined to mostly contain maghemite phase. Based on the dissolution tests, the best results were obtained using concentrated HCl (37.19% removal), 10% H_2SO_4 (14.07%), and HNO_3 – 20% HCl (11.38%).

Conclusion

The corrosion products in the investigated heat exchanger show remarkable resistance to most acidic solutions with the most successful removal methods including the use of a highly corrosive solution containing Cl^- ions. The use of these solvents with suitable flow rates and corrosion inhibitors can, therefore, help remove the corrosion products while also protecting the substrate.

Preservation of Stainless-Steel During and After Hydrotesting

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The preservation of stainless-steel piping or equipment after conducting a hydrotest is crucial to ensure the long-term integrity and reliability of the component. Hydrotesting is a common practice in the industrial and construction sectors to verify the integrity of piping, vessels, and other stainless-steel components. However, the exposure of stainless steel to water during hydrotesting could lead to potential issues, such as accelerated corrosion or cracking, if not properly managed.

Objective:

This paper examines the importance and recommendation of preserving stainless steel after conducting a hydrotest and provides recommendations on the water quality and maximum water contact time requirements during hydrotesting. It highlights various factors that can influence the deterioration of stainless steel due to hydrotesting, including water chemistry, presence of contaminants and exposure duration. Additionally, this paper emphasizes the importance of maintaining water quality standards, such as chloride level, dissolved oxygen, pH and the absence of contaminants to minimize the risk of corrosion or cracking during hydrotesting and subsequent preservation process.

Results

The recommended preservation strategies including the adherence of water quality used for hydrotesting, thorough cleaning and drying, the use of corrosion inhibitors, and the implementation of proper monitoring procedure would optimize the performance, reliability, and lifespan of stainless-steel equipment, ultimately leading to cost savings, improved operational efficiency, and enhanced safety and sustainability.

Conclusions and Significance of The Work

By adopting these best practices, organizations can ensure the long-term reliability and performance of their stainless-steel equipment and piping, ultimately leading to cost savings, reduced maintenance, and enhanced safety in their operations.

Neutron Moisture Detector for Corrosion Under Insulation (CUI)

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Corrosion under Insulation (CUI) is external corrosion due to the collection of water in annulus spaces, between the insulation and the metal surface. CUI cannot be eliminated, but it can be managed. This abstract shows the efforts toward managing CUI, through addressing field experience derived from the CUI Management Program.

The purpose of the deployment was to prove that there could be smart solution to proactively detect and prevent CUI on insulated pipes & equipment through a simple NDT device and its related inspection practice. The technology resulted in a successful identification of a hidden leak and served in rectifying the line before a sever CUI is created.

Introduction of CUI & its Challenge:

Accumulated moisture within the insulation does not only create the CUI but also lead to a deficiency in the thermal properties of the insulation (introducing conduction) where heat dissipation will be expected which can affect the process and the energy conservation.

This Technology indirectly detect CUI by measuring the moisture trapped under the weather jacket for insulated pipes and vessels

Therefore, and as the major factor of CUI has been pointed out to be the moisture ingress or accumulation within the insulation system, it was targeted to study and try some solutions that detect the water or any liquid accumulation within the insulation system before CUI take place.

A smart device, known as “NEUTRON MOISTURE DETECTOR” has been deployed address this challenge.

Technology Deployment Implementation:

The validation exercises were performed utilizing this technology followed by removing insulation to validate the presence of the moisture. The technology was reliable and it accurately predicted the presence of the moisture.

Technology Benefit

As CUI consider one of most corrosion challenges. The use of neutron moisture detector will support mitigating CUI.

- The technology is reasonably accurate, fast and inexpensive to screen insulated structures from trapped moisture
- This measurement is a proactive approach to prevent CUI from materializing by eliminating the conditions that can lead to CUI
- The moisture under insulation can be detected and the root cause for its presence is identified and rectified before the moisture causes corrosion
- This deployment was successful appellate to change the inspection approach from reactive to proactive that will have positive impact on plant asset integrity

Safety

This technology was executed in accordance with the national regulations and the international best practices

- Radiation Practice License
- Supervision of certified Radiation Protection Officer (RPO)
- Trained personnel

Electrochemical Behavior of Corrosion on borided and Non-borided Steel Z80 WCrV Immersed in NaCl 3.5% and HCl Solutions

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In this study, the corrosion resistance of Z80 WCrV 18-04-01 borided and non-borided steel was estimated in using linear polarization resistance (LPR) and electrochemical impedance spectroscopy (EIS) techniques. The boriding of the steel samples was carried out by the powder boriding method at 1223 K during 1h, 2h and 8h of exposure. Structural examinations of the surfaces of borided steel showed the presence of a double layer of FeB / Fe2B which is formed on the Z80 WCrV 18-04-01 steel. The linear polarization resistance and the EIS of the surfaces of borided and non-borided steel were performed in a corrosive solution of 1M HCl (PH = 0.13) and a saline solution of 3.5% NaCl. EIS data were analyzed for 7 days of exposure in both solutions.

The impedance curves obtained during this period for borided and non-borided steel were modeled by using equivalent electrical circuits. The results of the two electrochemical techniques indicated that the boride layers formed on the steel surfaces effectively protect the samples from corrosive effects in both environments only on the first day of immersion.

The effect of Mg and Sr addition on the microstructure and hydrogen embrittlement of Al-Si coating for hot stamping steels

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Recently, hot stamping technology has been increasingly used in automotive structural parts with ultra-high strength steel to meet the standards of both high fuel efficiency and crash worthiness. However, one issue of concern regarding these martensitic steels, which are fabricated using a hot stamping procedure, is that the steel is highly vulnerable to hydrogen delayed cracking caused by the diffusible hydrogen flow through the surface reaction of the coating in a furnace atmosphere. It is well known that the delayed fracture occurs especially due to hydrogen uptake during the hot stamping process in the case of Al-Si coated steel sheet . One way to make progress in understanding hydrogen delayed fractures is to elucidate an interaction for coat surface characteristics with diffusible hydrogen behaviour. In this study, in order to reduce the hydrogen uptake and delayed fracture during hot stamping this issue, we investigated effect of Mg and Sr addition in Al-Si coats on the hot-stamped boron steels. The main purpose of this study is as follows: (1) estimate the diffusible hydrogen uptake during the hot stamping procedure and (2) evaluate the hydrogen embrittlement susceptibility depending on the differential chemical composition and microstructure characteristics of newly developed coatings for the hot-stamped boron steels. As a results, the addition of Mg and Sr is effective to supress hydrogen uptake in respect of aluminium oxidation reaction in the furnace. Also, the hydrogen embrittlement was evaluated using slow strain rate test, the elongation reduction rate was improved by addition of Mg and Sr. It seems that the Mg and Sr oxide was preferentially formed on the outermost coating surface. In addition, it can be assumes that the pores on the coating surface were mostly disappeared.

Keywords: hot stamping process; hydrogen embrittlement

Development of Nanoparticle-Modified Nickel Coatings by Electrodeposition

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Among the various nanoparticle-modified coatings, nickel coatings are widely used in different industrial applications due their excellent corrosion resistance, high thermal conductivity and low resistivity. Although Ni coatings have good mechanical and corrosion resistance, the incorporation of nanoparticles can further improve their performance, for example by providing effective protection in aggressive media containing particulate matter.

To address this, our objective is to develop coatings with improved wear resistance under conditions of corrosion/erosion and tribocorrosion. This will be achieved by incorporating SiC nanoparticles and carbon nanotubes (CNT) during the electrodeposition process, utilizing various electrochemical parameters. In this study, high-performance Ni/SiC-CNT composite coatings were prepared on the surface of A36 carbon steel through direct current electrodeposition accompanied by ultrasonic stirring and mechanical stirring, and compared them with conventional pure nickel coatings.

Based on the research, the following conclusions are drawn. Scanning microscopy studies of coating samples clearly showed that both conventional Ni coatings and Ni/SiC-CNT composite coatings have uniform and fine surface morphologies, and the composition of the coatings was confirmed by EDS analysis. Based on the Vickers microhardness test, it is concluded that the microhardness of the Ni/SiC-CNT composite coating is higher than the Ni coating and much higher than the carbon steel substrate. In addition, in the electrochemical test in 0.5M NaCl solution (pH 7.3), the open circuit potential and anodic potentiodynamic polarization studies showed that the Ni/SiC-CNT coated sample exhibited higher corrosion resistance compared with the Ni coated sample. In erosion-corrosion experiments, carbon steel corroded seriously over time; Nickel coating can provide protection, but its anti-corrosion ability gradually weakens; Ni /SiC-CNT coating has the best anti-corrosion ability, and the corrosion rate remains stable and low. Therefore, it can be inferred that the corrosion protection ability of the coating is enhanced due to the reinforcement of nanoparticles.

Self-Regulating Electrodeposition of Ni-Mo Coatings

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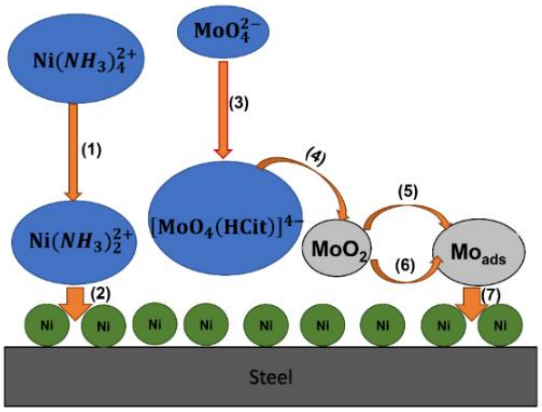
Nickel-molybdenum coatings are characterized by high thermal and corrosion resistance, microhardness, and catalytic activity in the hydrogen evolution reaction.

The purpose of this study was to study the influence of electrolysis parameters on the chemical composition and morphology of Ni-Mo coatings obtained from self-regulating electrolytes and to establish the limiting reactions of their formation.

Electrochemical Ni-Mo coatings have been obtained on a low-carbon steel substrate using self-regulating electrolyte containing 0.2 M $NiCl_2$, 0.3 M $Na_3C_6H_5O_7$, and 0.04 M $SrMoO_4$. The effects of electrolyte pH, temperature, deposition current density, and hydrodynamic conditions on chemical composition and morphology of the coatings were studied. It was established that a satisfactory coating can be obtained from this electrolyte at a current density of 0.5 A/dm^2 and a pH of 9.0. Under such conditions, a uniform, defect-free coating with a molybdenum content of ~25% was formed. Increasing the temperature and mixing speed increased the content of molybdenum in the coating, but its adhesion to the substrate decreased at its concentration <28% mass.



Electrochemical studies made it possible to clarify the mechanism of nickel-molybdenum coatings formation from complex ammonia electrolytes and the phasing of deposition reactions (figure). It was established that the rate of reduction of coatings in alkaline ammonia solutions is determined by the following chemical reaction of the reduction of molybdenum (IV) oxide to adsorbed molybdenum, which is limiting.

The proposed electrolyte is characterized by high stability, technologically and environmentally safe and its use makes it possible to obtain coatings containing from 2 to 58% mass. molybdenum.

Effect of Coating on Metallic Materials-Based Separator Plates to Enhance Corrosion Resistance and Hydrogen Permeability

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Abstract: Proton Exchange Membrane (PEM) fuel cells operate through the chemical reaction of hydrogen and oxygen to generate electrical energy. At standard temperature, PEM is recognized for its higher energy conversion efficiency compared to heat engines. To achieve such high efficiency, the role of the metal separator plate, a multi-functional component in fuel cells, is crucial. The metal separator plates supply reactant gases for the chemical reaction and also provide electrical conductivity. Recently, stainless steel and titanium-based separator plates are chosen for their electrical conductivity, low density, high mechanical strength, and low hydrogen permeability. In particular, these metals exhibit high corrosion resistance in a PEM fuel cell environment due to the formation of a stable and protective metal oxide film on their surfaces. However, the metal oxide film is electrically insulating, leading to a reduction in the electrical conductivity of the metal separator plates. To enhance the conductivity of the metal separator plates, a noble material coating is applied to remove the metal oxide film and reduce the plate thickness for cleaning or etching the metal surface [1].

In this study, the effects of Au and Pt coatings on metallic material-based separator plates were investigated to enhance corrosion resistance and hydrogen permeability. The corrosion resistance of metallic-based separator plates was compared based on the type of metal and coating materials through electrochemical analyses such as Open Circuit Potential (OCP), potentiodynamic and Electrochemical Impedance Spectroscopy (EIS) tests. Hydrogen permeability was compared based on the type and thickness of the metal separator plate, and the effectiveness of reducing hydrogen permeation by coating was confirmed.

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Effect of the saccharin concentration on electrodeposition of the Fe-Ni alloy

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Abstract

The FMM (Fine Metal Mask) used in the OLED display manufacturing process is a metal sheet with holes formed to allow the deposition of diode material only in the sub-pixel area. To prevent deformation and misalignment of the FMM (Fine Metal Mask) caused by heat during the RGB organic deposition process, an Invar plate with a thermal expansion coefficient (CTE) close to 0 is used. The Invar sheet applied to the current FMM is manufactured through a metallurgical process, and its final thickness after rolling is 20 micron. However, due to limitations in reducing thickness with the rolling process, for manufacturing FMM with a thickness of under 10 micron for next-generation high-resolution (UHD-level) displays, the bottom-up electroplating process is suitable. However, to maintain the shape of the electroplated Invar sheet while ensuring commercial-grade low CTE, heat treatment at temperatures exceeding 600℃ for an extended period is required, utilizing thermo-mechanical processing methods. If uniformity in the microstructure composed of nano-grains is ensured in the electroplated Invar alloy in the As-deposited, it is possible to increase the efficiency of the process by reducing the heat-treatment processing cost.

Therefore, in this study, we investigated the microstructural evolution in the Invar alloy by controlling the surface stress of the electroplated layer during pre-plating. We controlled the key additive, saccharin, in the Fe-Ni alloy electrolyte to assist the diffusion of iron and nickel ions. By examining the relation between microstructural uniformity, determined by the plated layer, and CTE, we propose optimized process conditions for the pre-plated Invar sheet.

Surface characterization of Fe-Cr-Ni-Si-P coatings resistant to wetting and liquid zinc corrosion during batch hot-dip galvanizing

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Abstract

Hot-dip galvanizing enhances steel corrosion resistance through the formation of protective zinc coatings. In batch galvanizing, steel parts are coated with zinc after several surface preparation stages. Steel hangers move the components from one bath to another, where they experience the same treatment and react with zinc, but cyclically. It's also necessary to clean the hangers in HCl in between galvanizing cycles. This process results in chemical waste, excessive consumption of zinc, and hangers' weight loss due to the formation and subsequent dissolution of Fe-Zn intermetallics. To address this, we aim to develop a zinc-resistant hanger material, focusing on SiO_2's potential to reduce wetting and zinc use in the galvanizing process.

Fe-Cr-Ni-Si-P coatings produced through the slurry process have a multiphase, complex microstructure consisting primarily of Cr- and P-rich phases scattered throughout a matrix of Ni- and Si-rich phases. Cyclic galvanizing tests revealed that those coatings decreased liquid zinc corrosion by 81% after 20 cycles, in comparison to the low-carbon DD13 steel. The wetting is also significantly reduced, with 85% less zinc consumed after 20 cycles for coated samples.

This presentation will be centered around SEM-EDX surface analysis of samples at different stages of galvanizing treatment. They reveal that the P-rich phases are resistant to liquid zinc corrosion, whereas the matrix forms rare Fe-Zn intermetallics. At the same time, the matrix is responsible for the creation of a thin layer of protective oxides that reduce the wetting by liquid zinc.

These coatings present a real interest for their application in batch galvanizing sites in order to increase production productivity and decrease waste since the slurry process can be adapted to parts of different sizes and geometries.

Investigating the anticorrosion property and water uptake of ceramic epoxy coatings via Electrochemical Impedance Spectroscopy (EIS)

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Corrosion is the major cause of defect and failure in pipelines freshwater and seawater mains of Hong Kong. Applying internal lining in pipes remain to be one of the most cost-effective ways to prevent it. Epoxy-based coatings are commonly applied as an internal protection lining for these pipes but due to its porous structure and hydrophilicity, seawater can still diffuse to the steel substrate and can cause localized corrosion. This study would like to assess the anticorrosion property and the ability to uptake water of two (2) industrial ceramic epoxy coatings--Ceramic Polymer (CP) 232 and Proguard CN 200, which are the coatings of interest of the Water Supplies Department of Hong Kong for future use in their seawater pipeline networks. These properties were obtained and analyzed using the results of the Electrochemical Impedance Spectroscopy (EIS) measurements after every 12 hours. Results showed that through time, the coating resistance of CP 232 decreased more than CN 200. Moreover, the coating resistance of CN 200 initially decreased, but increased afterwards thus possessing post-curing or self-healing ability when immersed in water. After 48 hours of immersion, it was found that CP 232 and CN 200 had 7.34% and 1.64% of water in their volume, respectively. These results will be the benchmark when additional active ingredients are added to the ceramic epoxy matrix to check if the anticorrosion property of the coatings improved.

Evaluation of the corrosion and tribocorrosion behavior in seawater of multilayers Cr/CrC/DLC/CNx/DLC deposited by HiPIMS on AISI 4317 steel.

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Abstract

Diamond-like carbon (DLC) and CrC coatings are used in various applications to reduce sliding friction, wear and corrosion of components such as bearings, which are an important part, for example, of machinery used in port facilities. AISI 4317 steel is used to manufacture these bearings, which suffer wear and corrosion due to the ions present in the marine environment. One way to increase wear resistance and reduce corrosion is to use multilayers coatings deposited by the high-power pulse magnetron sputtering (HiPIMS) technique with graded interfaces on each layer and apply metal ion etching to the substrate. This work reports the results of the open circuit potential measurements and potentiodynamic polarization tests used to evaluate the tribocorrosión and corrosion behavior of coated and bared samples. In the uncoated sample (AISI 4317) The OCP changed to less negative values when the slide began, this behavior could be due to the cyclic contact of the alumina sphere in the track area decrease the corrosion tendency in the wear track due to the continuous elimination of corrosive ions, avoid the formation of a double layer in the interphase metal-electrolyte. The sliding led to the formation of a galvanic couple, where the wear track acts as the cathode and the unworn area acts as the anode. The results show an improvement in the corrosion and wear resistance of the samples coated with the multilayers. Raman spectroscopy was used to study the DLC layer. SEM was used to observe the cross section and corroded surface of coated and uncoated samples of AISI 4317 steel. The structure of the multilayers was studied by XRD.

Flash-PEO coating on additively manufactured WE43 magnesium alloy

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Abstract:

Mg alloy WE43 is one of most relevant alloys for bioimplants due to its good mechanical properties and biocompatibility. However, its low corrosion resistance requires the use of protective coatings. Additively manufactured (AM) Mg alloys present an additional challenge to an adequate degradation rate control. Plasma electrolytic oxidation (PEO) is based on the growth of an oxide layer by means of high voltages (300 V – 600 V) that incorporates various species from the electrolyte that can enhance corrosion resistance. Flash-PEO coatings are formed in treatment times <120 s, are relatively thin (3-7 μm) and economic from energy consumption point of view. They present interest as part of a multifunctional hybrid coating system on a Mg alloy implant, their role is to provide first level of protection. This study focuses on the development of flash-PEO layer formed in 60 s to investigate its effect on the corrosion behaviour of an AM WE43 Mg alloy after a heat treatment of 400ºC during 24 h. The substrate before and after the heat treatment is characterized using several techniques such as: optical and scanning electron microscopy (SEM), X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDS), atomic force microscopy (AFM) and transmission electron microscopy (TEM). The coatings were also characterized by SEM, EDS and XRD, their roughness was measured with an optical profilometer, and water contact angle measurements were performed. For the corrosion evaluation, electrical impedance spectroscopy (EIS) measurements were performed up to 3 days in a simulated body fluid (SBF) at 37ºC and hydrogen evolution was also evaluated up to 3 days. The results reveal the influence of the flash-PEO coating on the corrosion behaviour providing a comparative analysis with the substrate.

Preliminary nitric chemical treatment effect, on corrosion behavior of 316 stainless steel, in chloride solution contain glucose

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The aim of the present work is to study the effect of preliminary chemical treatment in nitric acid, on the corrosion of 316 stainless steel, used as implants, in 0.9 wt.% chloride solution which contains glucose. Chemical treatment in nitric acid three days of immersion at 22°C, while making the open circuit potential more noble in chloride solution containing one, two, and four grams/liter of glucose during the eight days of immersion at 37°C. Open circuit potential is bigger when the solution contains four grams/liter of glucose. The potential corrosion, of the samples underwent a preliminary chemical treatment, becomes bigger for those in immersion in chloride solution which contains two and four grams/liter glucose, and the corrosion resistance becomes the smaller for those in immersion in chloride solution which contains one, two and four grams/liter glucose, after one hour of immersion in chloride solution containing glucose. But after eight days of immersion of the samples underwent a preliminary chemical treatment the corrosion potential decease for the samples in immersion in the chloride solution contains one, two and four grams/liter of glucose, and the corrosion resistance decrease only for those in immersion in chloride solution which contain two and four grams/liter of glucose. A significant difference in corrosion morphology was observed between sample underwent a preliminary chemical treatment and that no underwent this treatment in immersion in chloride solution contains four grams/liter of glucose during the eight days.

Harnessing the Synergy of Ceria-Zirconia Nanoparticles and hBN Nanosheets to Enhance the Corrosion Resistance of MoS_2 Solid Lubricant Coatings

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Abstract

Molybdenum disulphide is a conventional solid lubricant material due to their layered crystal structure enabling easy shearing resulting in low coefficient of friction. Even though MoS_2 is highly lubricating, the corrosive nature and high oxidation tendency of this dry solid lubricant limits its application, especially in oxidising and humid environment. The present work focuses on the improvement of corrosion resistance properties of MoS_2 nanosheets coatings, while maintaining its excellent anti-friction properties by incorporating hexagonal boron nitride (hBN) nanosheets and ceria-zirconia nanoparticles (CZ NPs). A hybrid structure consisting of MoS_2, hBN and CZ NPs was prepared as a composite and multilayer coating. The coatings were characterized by FE-SEM, XRD, Raman spectroscopy and XPS. The inclusion of hBN and CZ NPs did not significantly alter the coefficient of friction (CoF) and wear for the composite and multilayer coatings. The composite structure and multilayer structure showed high long-term corrosion resistance while the latter had the highest resistance to corrosion and oxidation. The hybrid multilayer structure had the lowest corrosion current density and corrosion rate with 167 % enhancement in total impedance. In the hybrid coating, hBN acts as a physical and insulating barrier to the flow of corrosive ions and charge transfer, thereby delaying the edge site oxidation in MoS_2. In the MH30-CZ multilayer coating, the presence of CZ intermediate layer favoured the formation of insoluble $Ce(OH)_3$ precipitates, and further impeded the corrosion. The galvanic cell formation of MoS_2 with steel was suppressed due to the presence of insulating CZ NPs layers. The synergic effect of hBN and CZ NPs resulted in high long-term corrosion resistance of the coating. The MoS_2-hBN-CZ hybrid coating exhibits potential as a viable option for solid lubricant applications in humid environments.

Development and Evaluation of a Zinc-Rich Paint by Using Multi-walled Carbon Nanotubes

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Abstract

Corrosion is a natural process which destroys the metal surface. Organic and inorganic coatings together have been commonly used for corrosion protection of metals. Zinc-Rich Paints (ZRP) protect metal surface from corrosion both coupling with more active metal and inhibition by corrosion products of the zinc. In order to achieve corrosion protection, the electrical contact between zinc particles and the metal surface is very important for galvanic coupling between each other. The main objective of this study is to understand corrosion mechanism on the metal surface and to develop more environmentally friendly coating which can enhance the corrosion protection. In this study, it was inspired to design a more environmental friendly anticorrosive coating and it was questioned to find a way to decrease zinc amount in the ZRP. Multi-walled carbon nanotube (MWCNT) was implemented into conventional ZRP to achieve above mentioned goal. It was obtained that, with 0.07 gram addition of MWCNT dispersion into the 109.33 gram ZRP, resulted in the best corrosion resistance performance amongst all.

Characterization of Edge Protection Improved Cathodic Electrodeposition Coatings

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Abstract

Cathodic electrodeposition is a method of applying a protective coating onto a conductive object using electric current. One of the consistent challenges of electrocoat formulations is the lack of high edge coverage and protection. Conventional products with limited sharp edge coverage have mild protection. On the other hand, high-edge products can prevent rust formation on the edges under severe corrosive environments that simulated with salt spray and cyclic corrosion tests. Controlling the edge corrosion performance of cathodic electrodeposition paint involves several considerations and strategies to ensure uniform and effective coating, especially in sharp edge areas prone to corrosion. Restricted flow during liquid cure phase is one of the key parameters in formula side. As a result of intrinsic surface tension, the film shrinks and flows away from the edges during curing. This phenomenon leads to thinner protective films and lower corrosion protection in these areas. By using rheology additives, it is possible to improve the corrosion edge protection of CED products. Products formulated with various rheology additive types are on the market. Those products could be graded as conventional, mid-edge, and high-edge products. The aim of this study is to evaluate the characterization of these products using analysis techniques such as Electrochemical Impedance Spectroscopy (EIS), measuring melt viscosity changes and cure characteristics, and cross-section DFT.

Influence of Nanoparticles on the Antifouling Properties of Organic Coatings

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Abstract

Organic coatings are the most common method used to protect metals from corrosion. In practice, there is a constant need to extend the protection life as well as to achieve some additional properties, such as better mechanical, chemical, and antimicrobial properties. Nanocomposite coatings are designed to provide effective and functional solutions for different challenging environments. The paper investigated a nanocomposite system for corrosion protection consisting of epoxy matrix coating and nanoparticles of metal powder. The effect of corrosion protection performance of nanocomposite was analyzed using scanning electrochemical microscopy (SECM) and electrochemical impedance spectroscopy (EIS). Nanocomposites improve mechanical, anticorrosive, and antimicrobial properties, providing better resistance to external mechanical influences and effectively preventing corrosion and bacterial growth. A multi-criteria evaluation of the stability of such systems was carried out and the one that shows the best corrosion and bacterial resistance was determined.

Keywords: nanoparticles, epoxy matrix, corrosion, antibacterial properties, SECM

Electropolymerized conducting polyaniline coating on nickel-aluminum bronze alloy for improved corrosion resistance in marine environment

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Abstract:

In this work, polyaniline (PANI) conducting polymer was deposited as a protective layer on a nickel aluminium bronze (NAB) alloy using the galvanostatic electropolymerization method at different current densities. The deposited coating was characterized by various techniques such as FTIR and SEM. To evaluate its effectiveness in corrosion protection, the anticorrosion properties of different PANI coatings were investigated in a 3.5 wt% NaCl solution by both potentiodynamic polarization and electrochemical impedance spectroscopy (EIS). The electrochemical results revealed that the PANI coatings acted as a barrier against the corrosive species and provided significant corrosion resistance against NAB degradation, with an inhibition efficiency of about 93%. Furthermore, corrosion protection was found to be dependent on the coated film and optimum corrosion inhibition was achieved under the test conditions for films deposited at a current density of 5 mA. cm^{-2}. Moreover, Raman spectroscopy confirmed the presence of the partially oxidized conductive polyaniline, the emeraldine form and its polaron structure, on the alloy surface. In addition, atomic force microscopy (AFM) was used to monitor the changes in the microstructure of the coating after exposure to the saline environment and demonstrated the formation of a robust coating with a significantly lower (5 times) surface roughness of the coated alloy than the uncoated surface after immersion.

Keywords: Electropolymerization; Conducing polymers; Nickel-aluminum bronze alloy; Raman spectroscopy; AFM, Corrosion protection

Chromate-free Paint Formulations: Factors Affecting the Release of Protected Organic Inhibitors

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The use of aluminium (Al) alloys is crucial to the aerospace industry due to their high mechanical stability at low material density. However, the addition of alloying elements increases the susceptibility of the Al alloy to corrosion. In commercial airplanes, corrosion prevention has been relying on the chromates (Cr(VI)) in the past decades which are aimed to be replaced by less hazardous and more sustainable alternatives. A ready to use alternative to chromates is not available that is as effective in the prevention of corrosion. This study aims to provide an understanding on the impact of paint formulation on Cr(VI)-free organic inhibitor release and corrosion protection performance.

A 2K epoxy-amine-based model coating formulation with protected organic inhibitors was modified systematically by varying the cross-linking ratio, inorganic filler content and the inhibitor loading. Protected organic inhibitors were selected, as pure organic inhibitors are prone to react with the polymeric backbone of the coating formulation. Leaching studies with free films were performed to investigate the release behaviour of inhibitors by exposing them to different media to simulate various corrosive environments. Inhibitor leaching was studied over time using Ultraviolet-Visible Spectroscopy (UV-Vis). In order to link complementary paint properties with the release behaviour, free films were studied using Differential Calorimetric Analysis (DSC) and Thermal Gravimetric Analysis (TGA). In addition, electrochemical methods were employed to assess the active corrosion protection of the inhibited model coating formulations on TSA treated AA2024 Al substrates. Defects of different sizes were introduced in the protection scheme for further investigations of the release behaviour on active corrosion protection performance of the coating formulations.

Tuning the colour of topcoats

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Keywords:

colour of topcoats, colour stability, aging tests

Abstract

The primary function of coatings is to protect the coated material against corrosion. However, aesthetic properties, mainly colour and gloss, are also a very important issue for users.

All new coatings are tested against the effects of various factors. To ensure colour stability, various types of aging tests are most often performed, based on a combination of changes in three basic parameters: temperature, humidity and UV radiation. The project, with the acronym ColourTune, aims to investigate which of the listed parameters has the largest share in the loss of colour stability, and then to answer the question of how to modify the composition of paints to obtain an optimal formulation.

In the first step of the project, samples were prepared in three colours: blue, red and yellow. Additionally, each colour was formulated with three different pigments. Before the aging tests, the coatings were characterized by many methods (e.g. colour and gloss measurements, 3D profilometry, SEM, WUR, stressmeter, etc.).

In the next step, the obtained coatings were aged in 7 different programs, during which UV intensities, temperature and humidity were modified. After weathering, the coatings were again characterized by the methods described in first step.

The results of the first stage of weathering and the resulting further plans for modifying the formulation of the coatings will be presented.

The research results presented in this paper are carried out as part of a project funded by the National Center for Research and Development under the Cornet Initiative.

Antimicrobial protection in powder coating for composite materials

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Abstract

Currently, silver, also in the form of nanoparticles, is most commonly used for antimicrobial protection of powder coatings. Despite high antimicrobial activity, these solutions have a number of disadvantages: the cost of the precious metal and its limited resources, immunotoxic potential and its bioaccumulation.

Taking into account the environmental aspects and sustainable development, it is important to develop new products dedicated to the surface protection of polymer composites – more environmentally friendly and with a good antimicrobial and anti-corrosion properties.

The paper will present the preliminary research results of an ongoing project with the acronym MicroSafeCoatings, the aim of which is, based on natural and synthetic substances with antimicrobial properties, produce more ecological (0% VOC emissions) and economic alternatives (2-5% waste, one layer of painting, painting and hardeninig time 2-10 minutes) products for protecting composite surfaces compared to the currently most widely used antimicrobial solvent-based coatings based on nanosilver (VOC emissions up to 60%, waste 10-20%, 2-3 layers of paint, painting and drying time 2-10 hours).

The presented results are performed as part of a project funded by the National Centre for Research and Development under the Cornet Initiative.

Nanometric-Scale Surface Morphology Manipulation Using Ultrashort Laser Pulses for Energy Storage Applications

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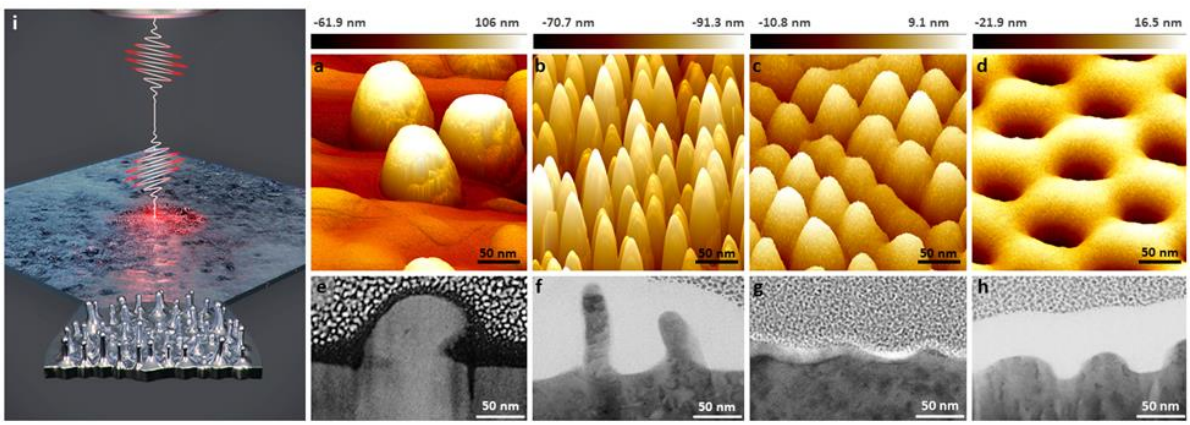
The utilization of ultrafast lasers to irradiate surfaces presents a self-organizing system, generating intricate micropatterns and nanopatterns. Dissipative structures manifest as diverse nanostructures, such as nanopeaks, nanobumps, nanohumps, and nanocavities, with transverse sizes ranging from 20 to 80 nm and heights up to 100 nm. This study investigates the formation of these structures under femtosecond laser irradiation, emphasizing precise control of the energy dose. Notably, nanopeaks exhibit exceptional aspect ratios on the nanoscale. The introduction of crossed-polarized double laser pulses adds an extra dimension to nanostructuring. The research demonstrates how laser energy dose and multi-pulse feedback influence the energy gradient distribution, surpassing critical values for surface self-organization. Controlling initial surface roughness is highlighted as a key factor in transitioning between self-organization regimes. The diverse nanostructures produced hold potential for unique surface functionalizations, particularly in manipulating properties on a nanoscale for energy storage applications. This work focuses on exploring the potential of self-organized nanostructures specifically in the context of energy storage.



Engineering ZIF-8 Thin Films for Corrosion Protection of Metal Surfaces

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Controlling the growth of in-situ metal-organic framework (MOF) thin films on metal surfaces remains a formidable challenge. Of particular interest among MOF subcategories is the zeolite imidazole framework (ZIF), which has garnered significant attention in diverse research fields, including separation and sensing. However, continuous ZIF crystal thin films require binding sites for desirable heterogeneous nucleation. This study proposes a novel and facile surface treatment process based on zinc-phosphate conversion coating at room temperature to facilitate the nucleation of ZIF-8 crystals on mild steel surfaces, thereby producing a corrosion-protective layer. The resulting thin layer offers a superior protective barrier film that can endure a harsh corrosive environment of salt spray for up to ten days. Electrochemical impedance spectroscopy (EIS) results demonstrate a total resistance of nearly 100 kΩ.cm^2 after 72 h immersion in 3.5% wt. NaCl solution, presenting a remarkable achievement compared to conventional primer coatings. Notably, the proposed primer enhances the total resistance of an epoxy coating by 135% following a deep mechanical scratch on the coating, significantly improving its anti-corrosion ability. This facile approach is transferable to other ZIF-based MOFs. **Figure 1** shows the successful synthesis of ZIF-8 crystals on the metal substrate, along with anti-corrosio properties.

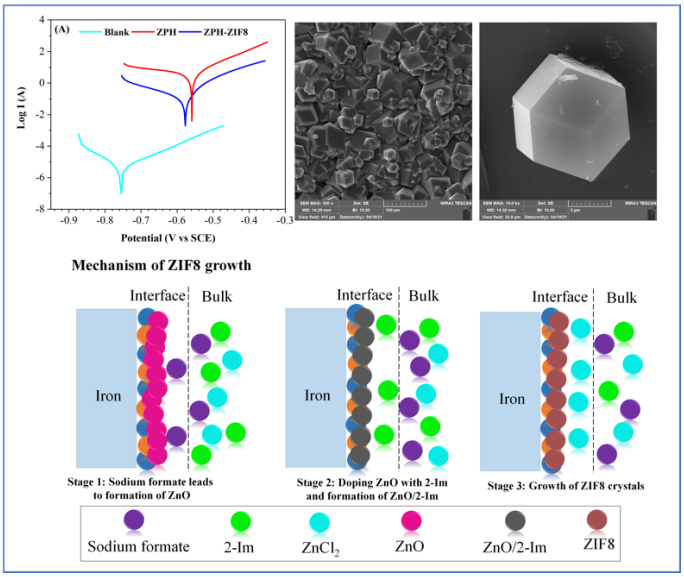

Figure 1. The successful synthesis of ZIF-8 crystals on the metal substrate, along with anti-corrosio properties

Evaluation of cathodic disbondment in a self-healing coating using electrochemical impedance spectroscopy

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The purpose of this work is to evaluate the performance of an epoxy coating supplemented with nanocontainers under cathodic disbondment conditions. Nanocontainers were made of a nanostructured ZnO core, filled with *Mimosa tenuiflora* extract, and a shell of a complex iron-tannic acid compound. Fourier Transform Infrared spectroscopy and Scanning Electron Microscopy were carried out to verify the composition and morphology of the nanomaterials. The performance of the defect coatings including 0.5, 1 and 2% of nanocontainers, when immersed in 3.5wt% NaCl, was measured by means of electrochemical impedance spectroscopy. Additionally, coated samples in NaCl were evaluated under an overpotential of $E_{op} = -1.33$ V vs Ag|AgCl. The presence of nanocontainers in coated samples showed characteristic impedance spectra of systems controlled by charge transfer. The coated system presented Nyquist plots with smaller semicircles, hence lower corrosion resistance, after 7 days of exposure in NaCl. However, more stable impedance values were observed with the concentration of 1% of nanocontainers during the next 28 days. On the other hand, the presence of nanocontainers promoted a decrease in the impedance values when experiments were conducted under cathodic disbondment conditions after 28 days of exposure.

A Stable MOF-based nanocontainer with controlled pore size for smart epoxy anti-corrosion coating

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Abstract

Recently, metal–organic frameworks (MOFs) like the zeolite imidazole framework-8 (ZIF-8) have gained attention as pigments for anti-corrosive coatings. Compared to other MOF materials, ZIF-8 is easy to synthesize and has good chemical and thermal stability, thanks to its robust bonds. Furthermore, ZIF-8's high specific surface area and large pore volume, along with its pH-responsive release behavior, render it a promising smart container for the encapsulation of corrosion inhibitors for application in epoxy anti-corrosive coatings.

While ZIF-8 nanocontainers are recognized for their potential in encapsulating corrosion inhibitors, they encounter notable technical challenges. Firstly, it has been highlighted that the microporous nature of ZIF-8, despite offering a high specific surface area, but leads to mass transfer limitations due to small pore diameters. This limitation hinders the effective diffusion of molecules, thus underutilizing the surface area available for the adsorption of corrosion inhibitors. Secondly, the structural integrity of ZIF-8 is significantly affected in acidic and alkaline conditions. Some researchers theorize that the collapse of ZIF-8 structure could protect metal against corrosion due to release of its zinc nodes and 2-methylimidazole linkers, which have corrosion-inhibition properties. However, this theory contradicts the primary goal of using ZIF-8 as nanocontainers, as their effectiveness in storing and releasing corrosion inhibitors is compromised when the structure is damaged.

Herein, we designed a stable MOF-based nanocontainer (SMOF) with an enlarged pore size to address both challenges mentioned above. The Barrett-Joyner-Halenda (BJH) pore size distribution indicated the appearance of mesopores within the SMOF structures, while electrochemical impedance spectroscopy (EIS) and salt spray results showed high corrosion resistance of the coating containing SMOF loaded with benzotriazole corrosion inhibitors.

Effect of carbides (cementite and V-bearing carbides) on hydrogen diffusion and embrittlement behaviors of ultra-high-strength steel

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The purpose of this study is to show that the resistance to hydrogen embrittlement of conventional advanced high-strength steel (AHSS) can be significantly improved by reducing cementite precipitation and increasing the fraction of fine V-bearing alloy carbides with a size of less than tens of nanometers. The reduction of cementite results in an increased resistance to hydrogen evolution and ad/absorption rates on the surface. On the other hand, a higher fraction of V-bearing precipitates can effectively impede the diffusion of hydrogen atoms towards potential hazardous regions in the matrix.

This work provides mechanistic interpretations of the role of carbides in hydrogen diffusion and embrittlement behaviors of ultra-high-strength steel with a tensile strength of more than 1.5 GPa, based on microstructural characterization and various electrochemical analyses.

Paintability and Corrosion Resistance Evaluation of Cut-edge in the Automotive Body

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Abstract

The main cause of initial surface corrosion issues, despite the application of optimized materials and surface treatments tailored to the vehicle type/parts, primarily stems from defects in the surface treatment, such as plating or organic coatings. The most common cause of such defects is the formation of burrs at the edges during the metal manufacturing process. The shearing process is the method for separating materials in the automotive industry, and typically, all materials undergo shearing processes during various component manufacturing stages. However, since burr management is mostly qualitative at present, it is challenging to provide precise judgment criteria when issues arise. Therefore, in this study, we aimed to conduct corrosion resistance evaluations for burr-prone areas according to the material type and propose management criteria and methods accordingly. To assess the corrosion resistance of vulnerable areas in the electrodeposition coating, we analyzed the level of burrs on actual press parts and fabricated electrodeposition coating samples using simulated plate materials. The fabricated samples underwent electrochemical analysis of the edge areas, enabling a comparative assessment of the corrosion resistance of the electrodeposition coating based on the material type. As a result, it was confirmed that controlling the level of burrs led to an improvement in corrosion resistance, with particularly excellent corrosion resistance observed when applying galvannealed steel, surpassing the corrosion current criterion by over 40 times.

The Effect of Steel on Corrosion of Bimetallic FDS Joints for Automotive Body

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Key words: automotive steel, galvanic corrosion, FDS (Flow Drilling Screw)

Abstract

The application of lightweighting technologies is the essential factor in minimizing the carbon emissions and increasing energy efficiency in the automotive industry. Aluminium, as the lightweight material, is increasingly used for automotive parts, and mechanical fastening techniques become necessary for multi-material parts composed of aluminium and steel due to challenges in conventional welding. FDS is one of hybrid mechanical joining techniques specialized for accessing single side. However, galvanic corrosion of aluminium in FDS joints could occur due to the electrochemical potential difference in bimetallic contacts. Therefore, it is crucial to verify the corrosivity depending on the type of steel and the structural environments in FDS joints.

In this study, the corrosion properties of FDS joint between 6,000 series aluminium alloy (AA) and two types of steel were evaluated through a cyclic corrosion test following GMW14872 for 63 cycles. Corrosion thinning results of AA were compared when coupled with galvaanealed steel (GA) and cold rolled steel (CR), both having a tensile strength of 600 MPa commonly used in automotive body in Asia. The analysis was conducted in three areas as gap, interface, and underneath hardware to explore the corrosion level. As a result, GA increased the corrosion life of AA compared to CR coupled with AA by up to 2.5 times. In the gap region, the outermost joint between AA and steel exhibited the most significant thinning of AA among the three areas, with a reduction of 580 μm when coupled with CR, attribute to the galvanic and crevice corrosion effects. Additionally, it was found that corrosion cross-sectional extent of AA with GA in the gap region indicated 43% of that with CR. The zinc-based coating on FDS hardware prevented penetration from the salt solution, but side of the hardware acted as weak region, showing only 30% thickness after the corrosion test.

Effect of Chromium Alloying on the Corrosion Properties of Automotive Ultra-High-Strength Steels

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The application of ultra-high-strength steel (UHSS) to automotive parts has been expanded for the past years to meet the safety and environmental regulations by improvement of crash performance and weight reduction of car body. Therefore, the durability based on the anti-corrosion performance of UHSS has become an important issue as automotive makers expanded their warranty.

The multi-phases microstructure with martensite and bainite resulted from rapid cooling during heat treatment is the primary method to obtain the high strength of AHSS. Alloying with hardening elements such as carbon, chromium, molybdenum and boron can compensate the insufficient cooling rate in heat treatment of AHSS process. Therefore, these elements are widely used in UHSS. Chromium is the most available among the hardening elements due to relatively economic and lower influence on the performances such as forming, welding and painting. However, it is still unclear to understand the effect of chromium on the corrosion property of steel under the automotive corrosive environment.

In the present study, the corrosion behaviours of chromium-containing (about 1.0 wt.%) UHSSs were studied under automotive cyclic corrosion test (CCT), and it was found out that the chromium decreased the uniform corrosion with lower mass loss, but induced the localized pitting corrosion resulting early perforation. The acceleration mechanism for the localized corrosion by chromium alloying was summarized with surface analyses such as SEM, TEM and EPMA. It was concluded that the localized corrosion was promoted when chloride ions concentrate and form $CrCl_3$ salt at the defects of dense chromium-enriched rust layer, and then be acidified the tip of pitting by hydrolysis reaction under long lasting high-humid wet condition.

The effect of alloying element on corrosion resistance of recycled Al alloy

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Abstract

Recycled Al alloys in the automotive industry have attracted attention since fewer greenhouse gas emissions occur in the production flow of recycled Al. The drawbacks of recycled Al alloys are higher impurity levels and detrimental intermetallic due to the mixing of alloys, which can limit their applications due to component durability issues. Removing alloying elements such as iron and copper from recycled Al alloys is not easy and economical; hence, it is necessary to know the effect of each alloying element and intermetallic on the corrosion resistance of Al alloys. Optimized recycled Al alloy can be developed by finding the threshold amounts of alloying elements for desired mechanical properties and acceptable corrosion resistance. This study focused on the effect of Fe intermetallic and Cu percentages on the corrosion resistance of Al alloy. The corrosion resistance of alloys with similar Fe levels but different Cu percentages was compared to determine the threshold of Cu level. In addition, the effect of different Fe intermetallic (Alfa and beta) on the corrosion resistance of Al alloy was studied. The corrosion resistance of the alloys was examined by comparing the pit population and depth of corroded surfaces after the salt spray test.

Keywords: Recycled Al alloy; Fe intermetallic; Cu; Corrosion resistance; pitting.

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Experiments Design Technique for Mixing of Three Coating Blended Materials: Conventional Micro and Nanostructured Sized Metallic Powders

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Abstract

The objective of this study is to perform an experimental design to investigate the physical and chemical properties of mixing three metallic coating blended materials; Tungsten carbide cobalt (WC-12Co) of both conventional micro and nanostructured sized mixed with Inconel-625. The blended coatings were deposited by High Velocity Oxy-fuel (HVOF) to produce very hard microstructure coatings suitable in the protection of erosion-corrosion wear. Microstructural analyses of the produced coatings and erosion test was carried out to investigate the effect of different composition on the coating performance. The surface roughness of the produced coating was examined before the erosion test to determine the surface morphology. The microstructure of both powders and surface coating were investigated via SEM techniques.

Ultra-high supercapacitive energy storage in layered porous transition metal carbide

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Abstract

Supercapacitors comprise the benefits of batteries and double-layer capacitors are among the most rising candidates for high-energy and high-power energy storage applications. Recently, 2D transition metal carbides, an emerging family of materials with ultrahigh rate capability, capacitance, and corrosion resistance, have attracted much interest compared to other transition metal-based materials. However, pure 2D transition metal carbides are only reported as negative electrodes as they are easily oxidized at positive potential. A positive electrode with superior performance is necessary to develop a high-performance metal carbide-based asymmetric device. Herein, a high-performance $Mn_3C_2T_x$ cathode is prepared for the first time by controlled etching of Mn_3AlC_2. Materials characterization studies are performed based on electron micrographs and X-ray photoelectron spectroscopy. Porous $Mn_3C_2T_x$ enables stable operation at positive potentials because of its enlarged work function. An asymmetric device is developed with $Mn_3C_2T_x$ as the cathode and N-doped graphene as an anode, which exhibits a high energy density of ~125 Wh kg^{-1} at a power density of ~514 W kg^{-1}. The impadence study reveals its stability after 10000 cycles. The resulting device demonstrates an ultra-high supercapacitance of ~1448 F g^{-1} surpassing reported MXene electrodes-based devices.

Saved by soil? Investigation of reburial as a sustainable approach to iron conservation

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Archaeological iron objects are valued sources of knowledge about past cultures and are cherished by museum visitors worldwide. They are, however, often highly unstable and tend to degrade very rapidly after excavation. The fast rate of degradation is primarily ascribed to the presence of chloride, which must be removed to stabilize the objects. This is challenging since chloride is tightly bound in iron compounds deep in the thick corrosion layers. In addition, the corrosion layer is an essential part of the objects and should therefore not be damaged during treatment. The methods used today are in many cases inefficient, often highly resource-consuming, and expensive. This restricts the number of objects that are preserved for future generations. The project “Sustainable Stabilization of Archaeological Iron” attempts to rethink the approach to conservation. The aim is to enable the preservation of more objects sustainably by utilizing natural soil processes. It is well known that anoxic waterlogged peat soils are inhabited by iron-reducing bacteria. These organisms reduce iron(III) compounds, as are found in corrosion layers, while oxidizing organic material in their metabolism. By reburying objects in such environments the natural microbiological communities may facilitate the transformation of harmful corrosion products and the release of chloride, thereby helping to stabilize the objects. This poster will give an overview of the project and illustrate how it explores desalination, corrosion product transformation, and change in stability during treatment in a peat soil environment. Besides the importance for heritage conservation, the research may contribute to understanding how buried iron and steel structures are influenced by environmental changes such as oxic/anoxic transient phases.

A comprehensive investigation of outdoor-exposed bronze artifacts: a multi-analytical perspective

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This study deals with an on-site monitoring campaign carried out to assess the conservation state of the bronze installation 'Katarsis' by Magdalena Abakanowicz, which is part of the Gori Collection at the *Fattoria di Celle* (Santomato di Pistoia, Italy). The installation consists of 33 bronze figures, without heads or arms, empty inside as shells, arranged in 5 rows and exposed outdoor in the garden. This also makes it an interesting case study of atmospheric corrosion because each element presents different corrosion morphologies on the surface and different exposure to the environmental conditions.

Electrochemical Impedance Spectroscopy (EIS) was employed to investigate the corrosion phenomena and correlate them with exposure to environmental agents. The electrochemical behaviour of the bronze artworks was assessed, highlighting an overall good state of preservation and the good protective effectiveness of the corrosion patinas. Furthermore, the impedance data were analysed by means of an equivalent electrical circuit to model the corrosion mechanisms. Most importantly, the the EIS analysis were correlated with data collected from sensors for the monitoring of temperature and humidity installed close to the figures to provide information on the microclimate parameters. X-ray fluorescence was used to analyse the alloy, which showed a typical composition of bronze alloys used for artistic purposes. Meanwhile, Raman Spectroscopy was employed to identify the corrosion products on both the internal and external surfaces of the figures. The corrosion products were mainly sulphates and copper oxides, while basic copper chlorides were present in some sheltered areas. The ongoing monitoring campaign demonstrates the efficacy of the proposed approach in characterizing degradation processes and planning conservation strategies for outdoor bronze artifacts. The presentation will discuss achieved benefits, acknowledging the method's advantages, and addressing remaining challenges in developing tailored safeguard methodologies.

Increasing hot corrosion resistance of β-(Ni, Pt)Al coating by replacing Pt partially with Zr

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Due to its excellent oxidation resistance, β-(Ni, Pt)Al coating has been widely used as a high-temperature protective coating for key hot components of aeroengines (such as turbine blades). However, the hot corrosion resistance of (Ni, Pt)Al coating is insufficient, and the cost of the Pt is too high, as well as the oxide scale on the coating surface is prone to failure due to spallation in service environments. The low-cost reactive element Zr can not only promote the formation of oxide scale with high adhesion and low growth rate, but also reduce the harmful effects of sulfur. Therefore, in this work, Zr was used to partially replace Pt in (Ni, Pt)Al coatings to improve the service performance of the coating and simultaneously reduce the cost of Pt to some extent.

Pure (Ni, Pt)Al coating and low, medium, and high content Zr-doped (Ni, Pt)Al coatings were prepared on Ni-based superalloy by pulse electroplating combined with “above-pack” aluminization treatment and then subjected to hot corrosion tests in 75 wt.% Na_2SO_4 + 25 wt.% K_2SO_4 mixed salts at 900 ℃. The results showed that replacing Pt partially with Zr improved the hot corrosion resistance of (Ni, Pt)Al coating. After 200 h hot corrosion, the oxide scale thickness, the degree of scale spallation, the amount of the Al_2O_3 intrusions and corrosion depth of Medium-Zr coating and High-Zr coating were significantly lower than those of the Low-Zr coating and pure (Ni, Pt)Al coating, which indicated that Zr partially replacing Pt can not only reduce the growth rate of the oxide scale and improve its spallation resistance, but also inhibit the development of intrusions. This was attributed to that Zr ions segregation at the oxide grain boundaries reduced the oxidation rate and Zr inhibited the development of intrusions through the fixation effect of Zr on S. However, the growth of ZrO_2 particles in the oxide scale induced by over-doping in High-Zr coating leads to local scale spallation. This work provides new insights into coating design to improve coating performance and simultaneously reduce costs to some extent.

The effects of artificial aging on the impact response of innovative aeronautic carbon composites

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With the increasing utilization of polymer matrix composite materials in aeronautical components, understanding the effects of various environmental conditions on the impact behavior of composites is crucial for ensuring the safe design of structures. This study offers insights into the impact response of carbon composite samples following exposure to artificial aging simulating adverse atmospheric conditions. For this study, carbon composite samples were prepared using heated vacuum-assisted resin transfer moulding and stamping processes and submitted for inspection using non-destructive techniques such as visual inspection and computed tomography, and then these samples were divided into two groups (I and II) to be tested using two different artificial aging methods. A salt spray chamber was used to simulate exposure to maritime atmospheres rich in chlorides (samples group I), and to evaluate the behavior of these composites under different temperature and pressure cycles, samples group II underwent testing in a thermal cycle chamber. After artificial aging, impact tests were then conducted on the samples to characterize the influence of the environment on their impact resistance. To evaluate a possible chemical degradation, FTIR analysis was performed on the samples before and after the thermal cycle and salt spray chamber tests. The FTIR spectra obtained suggest that the samples remained stable when exposed to these adverse conditions. However, an increase in both mass and thickness of the samples was observed under these conditions. The computed tomography analyses confirmed the presence of defects resulting from manufacturing processes and various tests conducted during the study, such as disbonds, porosities, and marks resulting from the impact tests. The results obtained showed that the samples subjected to the salt spray chamber and later to the impact tests presented a higher impact mark when compared to the samples exposed to the thermal cycle chamber.

Acknowledgments:

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Impact of temperature and salinity on the corrosion of SAC solder joints

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Abstract

This paper deals with the influence of the temperature and the salinity on the corrosion of SAC solder joints in microelectronic assemblies. Corroded areas, electrical and mechanical resistance of joints are measured in various conditions of salt spray test.

Introduction

Assessing the thermal and mechanical performance of SAC solder is not sufficient to ensure the reliability of electronic assemblies. With the increasing miniaturization of electrical products and the multiplication of environments in which they are used, solder joint corrosion is becoming a critical factor in long-term use. Various studies are published on the corrosion of SAC solder joints in damp heat test and on the corrosion of tin-based alloys in a saline environment, but on a macroscopic scale. As a result, the behaviour of SAC solder alloy in salt spray needs to be studied in order to understand the evolution of the microstructure in this environment, and to determine if the salt corrosion can be responsible for electrical failure.

Corrosion test method

Representative electronic assemblies were submitted to saline environment in a salt spray chamber, under various ageing conditions: 5 temperatures from 25°C to 45°C and 3 concentrations of the saline solution with a sodium chloride (NaCl) near 5%. The electrical continuity is checked. The mechanical force necessary to shear the solder joints is determined. The corroded areas of the solder joints are measured by optical observations; the corrosion products are determined using X-ray diffraction analyses. The corrosion product obtained during the degradation process of SAC305 solder is $Sn_{21}O_6(OH)_{14}Cl_{16}$.

Conclusion

As expected, the temperature and the salinity rate are factors that accelerate the corrosion. Finally, the activation energies corresponding to corrosion phenomena in solder joints are computed thanks to the percentages of corroded surface measured and the mechanical force determined for each. An activation energy of 0.37eV is determined from the tests results at 5 different temperatures for a 5% salinity.

Pitting Corrosion of Carbon Steel Downhole Tubular Under Simulated Sour Gas Well Conditions

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Abstract

Sour gas alone does not promote pitting corrosion to carbon steel when a H_2S/CO_2 ratio was greater than 0.1. This critical ratio can be relaxed to 0.05 as other majors employ. It was found that sour corrosion was flow-sensitive but not to temperature. Reducing chloride ion level increased sour corrosion rate. As sour corrosion is not aggressive, carbon steel completions are still cost-effective for on-shore sour wells.

Keywords:Sour,gas,corrosion, pitting, carbon steel, corrosion inhibitor.sour,downhole

Evaluation Method for Materials in CCS Transportation Pipelines

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The International Energy Agency (IEA) emphasizes the significance of CCUS (Carbon Capture, Utilization, and Storage) among various means to achieve 2050 NET-ZERO. Globally, CCUS infrastructure is rapidly increasing based on national support policies and demonstration projects. As the infrastructure expands, intercontinental transportation is expected to take place using pipelines. Additionally, from an economic perspective, transportation utilizing high-density states (liquid, supercritical) is anticipated.

When considering materials for carbon dioxide transportation pipelines, there are two main considerations. First, materials capable of withstanding high-pressure transport are required. Second, due to variations in the composition of moisture and impurities depending on the location of carbon dioxide capture, internal corrosion resistance is necessary.

In this study, we aim to provide a description of the evaluation methods for materials used in carbon dioxide transportation pipelines. We have established actual CCS pipeline environment simulation equipment and considerations for constructing evaluation methods and equipment environments for pipeline materials. Through this equipment, we plan to assess the effect of pressure, impurities, flow velocity, and multiphase flow on materials.

CCUS, CCS Transportation Pipelines

Evaluation of Corrosion and Hydrogen Embrittlement in Martensitic Steel in CO_2 Environments

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The dissolution of CO_2 in water creates a corrosive environment for susceptible steels, but under certain conditions there is the possibility of $FeCO_3$ precipitation, which can mitigate corrosion. CO_2 can also contribute to hydrogen loading, increasing the rate of cathodic reaction compared to strong acid solutions at the same pH. As with CO_2 corrosion, the interaction of susceptible steels with H_2S in an aqueous medium can result in failures, such as those resulting from hydrogen embrittlement. Among the different methods used to control corrosion, cathodic protection stands out. Despite being efficient, oversizing the cathodic potential can lead to hydrogen absorption and metal embrittlement. Some factors contribute to increasing or decreasing the ease with which hydrogen solubilizes or diffuses into solid metallic materials, including the microstructure of the steel. Therefore, the study evaluated the performance of a martensitic steel, considering its use in confined CO_2 environments. The motivation for this study is the possibility of evaluating the behavior of an alternative microstructure, tempered martensite, using as a reference reinforcement wires with pearlitic microstructure used in flexible pipes. The methodology included electrochemical, SSRT and hydrogen permeation tests. The results indicated that increasing the temperature and CO_2 pressure favored $FeCO_3$ precipitation kinetics, but increased susceptibility to localized corrosion. The SSRT and permeation tests showed that the negative change in cathodic polarization potential from -800 mV (Ag/AgCl) to -1100 mV (Ag/AgCl), in ASTM D1141 solution, resulted in a reduction in area ratios, time to fracture and total elongation, as well as an increase in the effective diffusion coefficient and hydrogen concentration. In the presence of H_2S, the parameters for assessing susceptibility to environmentally assisted cracking and those obtained from the hydrogen permeation curves were more critical than the tests under cathodic polarization.

Abstract

"Corrosion behavior of commercial materials under CO_2 atmosphere at high temperatures for CSP applications"

M. Navas, E. Oñorbe, E. Muñoz, D. De Lucas

Ciemat (

A new development for a future commercial CSP plant aims to integrate concentrate solar power particle systems into highly efficient s-CO2 Brayton power cycles for electricity production, within COMPASsCO2 project. The viability of this new technology relies on the design and reliable material selection for the heat exchanger, such as a key component. In this context, the effect of the temperature and the differences of CO_2 purity grades (research and industrial grades) have been determined on corrosion behavior of the state of the art (SOTA) materials. Long-term thermal oxidation tests with CO_2 gas at atmospheric pressure have been performed at high temperatures with the following SOTA materials: Sanicro 25, Haynes 282, Inconel 740 and Inconel 617B. A study of the different oxide scales after corrosion tests for SOTA materials have been carried out. For the studied temperatures (700 °C and 900 °C) Haynes 282 presents higher weight gains than the rest of materials, followed by Inconel 617B and 740 with similar trend between them, and Sanicro 25 presents the lowest value, being negative in the case of 900 °C (poorly adherent oxide scales).

Challenges in Compatibility Testing of Materials for the CCS Industry

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Selecting suitable materials for carbon capture, transport, and storage (CCS) infrastructure—such as pipelines, gaskets, storage tanks, pumps, compressors, and valves— is vital for the effective, safe, and cost-efficient reduction of CO_2 globally. However, the lack of international test standards for CCS industry poses significant challenges. To obtain consistent and comparable test results that accurately simulate operational environments, a standardized and comprehensive testing approach is necessary. Key considerations include safety protocols, detailed test procedures covering material preparation (e.g., cleaning and polishing), temperature and pressure monitoring, the introduction and monitoring of impurities in the CO_2, flow dynamics, and systematic post-test analysis.

Force Technology has developed advanced test facilities to address these challenges, capable of evaluating materials in CO_2 environments with impurities (e.g., O_2, H_2S, NO_x, SO_x), under both aerated and de-aerated conditions, at pressures from 0 to 300 bar and temperatures from 0 to 300 degrees Celsius. This work emphasizes the importance of advanced testing protocols and interdisciplinary collaboration to enhance CCS system reliability and efficiency, for speeding up the deployment of effective CCS technologies, contributing to global carbon reduction efforts. In this presentation we will present the new facilities and discuss the challenges in designing and conducting reliable and reproducible material testing for the CCS industry. Also, few results from compatibility testing of steel material in CO_2 will be shown.

Characteristics of sulfide stress corrosion cracking of high strength pipeline steel

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Abstract

Recently, as mining environments have moved to extreme regions due to the decline in oil and natural gas resources, the demand for high-performance steel pipe products is increasing.

Among these high-performance steel pipes, in the case of oil well pipes, a method of excluding the heat treatment process can be suggested as a cost-reduction measure to secure competitiveness.

As the mining environment changes to extreme temperatures, excellent resistance to sulfide stress corrosion cracking (SSCC), which occurs when a fracture occurs at a load lower than the yield strength of steel due to an environment containing H2S gas, is required as a characteristic required for high-performance pipeline steels. Accordingly, in this study, X80 grade hot-rolled steels were manufactured for application to oil country tubular goods, and microstructure and SSCC resistance were evaluated.

To improve the strength and SSCC resistance of steel, precipitation strengthening and trapping of hydrogen are introduced through Ti-based MC precipitation with low carbon content. As a result of the analysis, the microstructure showed a dual-phase structure of ferrite and pearlite, as well as nanoscale Ti-based carbide inside the ferrite. It precipitated.

Accordingly, the strength satisfied the grade X80 with a yield strength of 620 MPa, tensile strength of 700 MPa, and elongation of 18%, and the SSCC test showed very excellent SSCC resistance as no fracture occurred even at SMYS 95% in the solution A environment.

Atmospheric corrosion behavior of Zn-Al-Mg coated steel

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Abstract Zn-Al-Mg (ZM) coating have been developed in recent years to improve the corrosion resistance of the material. In this paper, atmospheric corrosion tests of ZM materials were carried out in Turpan, Jiangjin, Qingdao and Wanning for one year and two years. By analyzing the morphologies, microstructures and chemical compositions of the corrosion products, the corrosion behaviors of ZM coating in different environment were investigated.

There are evenly distributed primary zinc phase, Zn-$MgZn_2$ binary eutectic phase and Zn-$MgZn_2$-Al ternary eutectic phase in ZM coating. The corrosion rates of ZM coating vary widely in different regions. In terms of the corrosion results for both 1 year and 2 years, the corrosion rate relationship between these four regions are Wanning > Qingdao > Jiangjin > Turpan. After 1 year of atmospheric corrosion, the corrosion rate ratio of hot-dip galvanized steel (GI) to ZM is 4.56 in Wanning, 3.76 in Jiangjin, 2.84 in Qingdao, and 2.42 in Turpan. After 2 years of atmospheric corrosion, the corrosion rate ratio of GI to ZM is 4.48 in Wanning, 4.05 in Jiangjin, 3.83 in Qingdao, and 1.60 in Turpan. These results indicate that ZM coating has better corrosion resistance than GI coating under the same atmospheric environment, especially in humid industrial atmosphere and offshore atmosphere with high chlorine. The different corrosion performances of GI and ZM coating are related to the types of corrosion products. In a high chlorine environment, the anodic dissolution of $MgZn_2$ in ZM coating releases Mg^{2+} ions. The dissolute Mg^{2+} can react with OH^- to form $Mg(OH)_2$, which inhibiting the pH increase at cathodic sites. It hinders the formation of loose ZnO and makes the protective corrosion product $Zn(CO_3)_2(OH)_6$ more stable. Therefore, it prevents the oxygen reduction reaction on the surface of the ZM coating and reduces the corrosion rate. This paper provides theoretical support for the promotion and application of ZM materials.

Key words：Zn-Al-Mg; Atmospheric corrosion; Corrosion products

The Bresle method as an option for determining the average monthly deposition of chloride ions

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There are several options available for determining the average monthly deposition rate of chloride ions, such as the wet candle method or dry gauze method as outlined in ISO 9225. These methods need to be laboratory-investigated. Titration or spectrometric analysis are possible options for determining the amount of chloride ions in the solution of the prepared sample after exposure.

Conversely, the Bresle method is used to determine the concentration of soluble salts on metal surfaces. This is an important test before applying protective coatings. Ensuring sufficient surface cleanliness before applying the protective coating helps prevent corrosion damage resulting from a contaminated surface.

This article explores the use of the Bresle method to determine average monthly deposition rates of chloride ions in different localities as an alternative to standard methods. Additionally, correlation and regression analyses are made for the wet candle method and the Bresle method. The authors highlight the advantages of using the Bresle method for chloride ion deposition rate analysis, such as its ability to capture local effects (e.g., details) in situ.

Ion selectivity of galvanic corrosion products formed in multi-material gaps

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The utilization of multi-material such as composites of carbon fiber reinforced thermoplastic (CFRTP) and high-strength steel or CFRTP and aluminum alloy is one of the main strategies for weight reduction in automotive body. However, multi-material is subject to galvanic corrosion, which increases the risk of failure and shortens its service life. In this study, corrosion products formed in the gap of multi-material were investigated by wet-and-dry cyclic tests simulating atmospheric corrosion of automotive bodies. The membrane potential of corrosion products was measured to evaluate the ion selectivity and to determine the effects of products on corrosion in the gap incidentally formed multi-material.

The multi-material samples consisted of a high-strength steel plate and CFRTP or A6016 aluminum alloy plate jointed with two plastic bolts and cation electrodeposition coating, with a gap of 0.1 mm between plates. The wet-and-dry cyclic tests, in which a sample was immersed in a mixture of NaCl and $CaCl_2$ solutions for 0.25 h and then repeatedly subjected to a wet atmosphere of 90%RH at 283 K for 3 h and a dry atmosphere of 35%RH at 298 K for 3 h, was repeated 28 times a week according to Kozaki [1]. After the wet-and-dry cyclic test, corrosion products filled the gap of the multi-material samples. The membrane potential of the corrosion products in the gap was measured using several NaCl solutions with different concentrations, and it was found that the products were anion-selective in all tests. The products formed in the test using dilute mixture solution showed greater fixed-charge concentrations than those formed in the tests with concentrated mixture solutions. Chloride ions promote galvanic corrosion on the metals of multi-material samples, and the resulting corrosion products formed in the gaps of the multi-material samples were found to play a promoting role in atmospheric corrosion.

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Weathering campaigns to determine corrosivity on offshore wind turbines

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ISO 9223 standard for the classification of corrosivity in atmospheres is based on the mass loss of standard samples. We are concerned with the question of which corrosivity categories for Fe-sheets can be found at an offshore wind turbine and where they are comparable with our offshore locations. Therefore, an offshore wind turbine was prepared inner and outside with steel samples according to ISO 9226 and the corrosivity was determined by mass loss after one of exposure. From the splash water zone to the top of the tower (helihoist), changes in corrosivity were determined and will be presented by a poster.

Weathering Campaigns for a Marine Corrosion Atlas

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Germany has set itself the task to become a world leader in green hydrogen technologies and is promoting the transition to a hydrogen economy. The H2Mare flagship project is exploring the offshore production of green hydrogen and other power-to-X products. One of the most important goals is the safe and cost-efficient operation of offshore infrastructures, where a service life of at least 25 years is aimed. However, the corrosive environment towards metallic materials presents challenges in marine areas.

The atmosphere at one location could be affected by the distance to the sea level and does not have the same corrosivity for all exposed materials. Creating an atmosphere corrosion atlas for marine environments by weathering campaigns aims to close this gap. Operators of offshore structures can use the data to estimate the corrosivity of the atmosphere on the construction site. ISO 9223 standard for classifying corrosivity in atmospheres is based on the mass loss of standard samples regarding ISO 9226 and uses corrosivity categories from C1 to C5 and CX.

Atmospheric exposure racks are located in different marine places in the North and Baltic Seas. The collected data are the foundation for the new standardization project. Sheltered samples are more critical regarding the corrosivity by the accumulation of corrosive ions and the absence of washing effects by rain. The North Sea location Windpark Hohe See is more corrosive than Helgoland, which shows the importance of weathering campaigns. The preliminary results indicate that the general assumption of extreme corrosivity (CX) at nonsplashwater-affected marine exposure is not tenable, and a more material and constructive consideration is beneficial.

In-Situ Observation For Chloride Induced Pitting Corrosion Nucleation On 304 Stainless Steel At Atmospheric Conditions

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One of most common used class of stainless steels is austenitic stainless steel due to its excellent corrosion resistance. This feature made austenitic stainless steel among the most optimum choices for various industries. The aim of this research is to observe chloride induced pitting corrosion nucleation in austenitic stainless-steel grade 304 SS at atmospheric condition. In particular, the objectives are to observe evaporation rate of NaCl droplets at different size and concentration using time-lapse images and generate graphs shows these relations. In addition, determine chloride concentration at which pitting may occur.

AISI 304 austenitic stainless steel one of most common used class of stainless steels due to its excellent corrosion resistance. However, in real life applications, many steel structures and equipment are exposed to atmospheric corrosive environment especially at coastal regions. As result, severe pitting corrosion might occur leading to a significant effect on integrity of the structures and causes safety concerns. In this research the observation of chloride induced pitting corrosion nucleation in austenitic stainless-steel grade 304 SS at atmospheric condition was conducted through two types of tests. Droplet evaporation rate tests and wet-dry cycle tests. Different volumes (10 µL and 20 µL) and concentrations (0.15M and 0.60M) of NaCl droplets were deposited by manual micropipette on the specimens. During each test, time-lapse images were taken using microscopic cameras. The results of conducted tests revealed that pitting corrosion might occur at an average relative humidity of 50% RH and temperature from 23oC to 24oC with chloride concentration range from 3M to 6M. Also, the droplet size has an effect on pitting initiation as a large droplet showed more possibility to have pitting corrosion than a small droplet.

Development of coatings for corrosion protection inside PEM electrolyzers

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Hydrogen demand is rapidly increasing as it enables large-scale storage of renewable energy. One promising approach to produce green hydrogen is by means of proton exchange membrane water electrolysis (PEMWE). While PEMWE exhibits several advantageous properties like a high gas purity, high efficiency and a rapid response time, it has one drawback compared to other hydrogen production methods (e.g. alkaline water electrolysis): its relatively high capital cost. One of the most cost extensive parts of PEM electrolyzers are the porous transport layers (PTLs) on the anode side which must withstand potentials up to 2 V and pH values down to 0. To mitigate corrosion of the PTLs and ensure long term functioning without performance loss, they are often made out of a high-cost titanium fleece coated with platinum.

This study therefore focuses on the reduction of materials costs for PEM electrolyzers by exchanging or reducing the expensive corrosion resistant materials currently used with abundant low cost materials. To this end, coatings made of different materials were deposited using magnetron sputtering (MS) and cold gas spraying (CGS) and are investigated regarding their microstructure and composition before and after undergoing various corrosion conditions. Finally, a novel type of PTL made of a stainless steel expanded metal was coated with titanium using CGS, thus reducing the total amount of titanium needed. Preliminary tests on laboratory scale PEM electrolyzers showed a comparable performance to the conventionally used titanium fleece. In addition, the performance of other corrosion resistant materials (e.g. niobium) as coatings of expanded metal PTLs will be shown.

Tunable Zinc Powder Anode with Advanced Additives for Enhanced Performance in Aqueous Rechargeable Zinc-Air Batteries

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Aqueous rechargeable zinc-air batteries (AZABs) offer significant potential for green energy storage due to their high theoretical specific capacity, volumetric energy density, and environmental friendliness[1]. Zinc anodes are key for efficient recharging and maintaining capacity over long cycles but face challenges like hydrogen evolution, passivation, shape change, and dendrite growth[2]. Mitigating dendrite growth involves depositing Zn onto 3D skeletons, designing coated interfaces, and using zinc powder instead of foil. Zinc powder, with its high surface area, reduces overpotential and enables precise control of energy density. Additives like Bi, K, and BiS improve conductivity and resist passivation, preventing dendrite formation[3].

In this study, zinc powders with various additives were synthesized and used as the zinc anode for alkaline aqueous zinc-air batteries. Additives such as Bi_2O_3, BiS, and K_2CO_3 were incorporated to enhance the performance and longevity of the AZABs. The base zinc powder anode comprises three main components: nanosized zinc powder for battery operation, cornstarch for shear thickening and electrolyte absorption, and polyethylene glycol with ethylene glycol as a binder. The morphology and electronic structure of the anode before and after cycling were analyzed using scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and Raman spectroscopy. Electrochemical tests were performed using a homemade zinc-air battery cell, featuring a zinc-powder anode, 6 M KOH alkaline electrolyte, and a high entropy perovskite oxide electrocatalyst-coated carbon cloth. Results indicated that the zinc powder anode outperformed the zinc foil anode in both specific capacity and charge-discharge stability.

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Evaluation of materials regarding their resistance and the impact of impurities on benzyltoluene (BT-D) and perhydrobenzyltoluene (BT-H) for storage tanks and pipelines

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Benzyltoluene is used as a so called liquid organic hydrogen carrier (LOHC). It can chemically bind a remarkable amount of hydrogen in the perhydro form, enabling transport and storage at ambient pressure and temperature. The binding or release of hydrogen occurs via a thermocatalytic process. Although benzyltoluene (BT-H) and in dehydrogenated benzyltoluene (BT-D) are chemically very inactive, for qualification purposes materials for storage tanks and pipelines have to be tested concerning their durability and the impact due to impurities by material dissolution. For this, immersion tests were carried out at 50 °C for mild steel DC04 and copper ETP R240 up to 24 weeks. Chemical analysis using ICP-OES has been performed to determine possible impurities in the benzyltoluene.

Study of fretting-initiated crevice corrosion and crevice corrosion affected fretting of stainless steel

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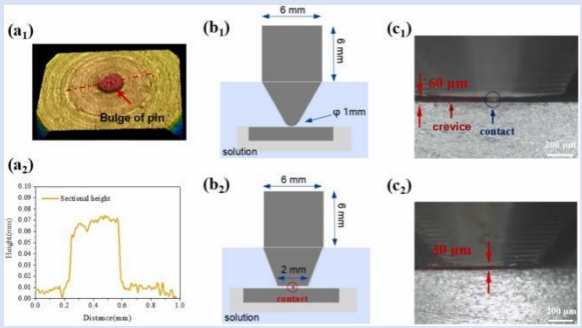
Abstract

Fretting crevice corrosion of total hip joints have been associated with joint replacement failure. However, researchers have not considered the interaction between fretting corrosion and crevice corrosion. In this study, an artificial crevice system that could perform fretting in the center of the crevice was designed, and fretting-initiated crevice corrosion (FICC) under different crevice widths, along with the effect of crevice corrosion on fretting corrosion, were studied. The results showed that FICC was more obvious under a smaller crevice, and pitting corrosion initiated at the shear band, resulting in crevice corrosion. Furthermore, corrosion pre-treatment significantly increased the fretting corrosion current.

Introduction

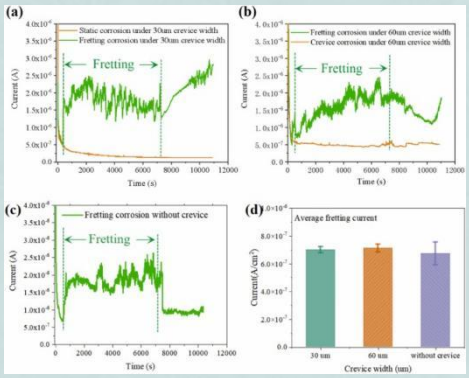
Assessments in clinical practice found that the fixed interfaces of the femoral stem and ball head (femoral stem and bone cement) of the artificial hip joint will undergo micron-scale slip during the loading process. This fretting wear will result in fretting corrosion due to corrosion by body fluids. Fretting corrosion can cause joint loosening and the release of metal ions, eventually leading to adverse local tissue reactions in the artificial joints. Furthermore, the secondary revision of artificial joints can result in economic pressure and pain for patients. Previous studies on fretting corrosion have often used ball and disk contact tests. However, the design of these tests did not consider the existence of crevices and could not simulate the real conditions of fretting crevice corrosion. In this study, an artificial crevice was formed after pin-disk contact using special pin samples, and fretting corrosion was performed in the center of the crevice.

Expermental methods



The columnar bulge 350 μm in diameter was located in the center of the plane of pin. In the actual test, only the columnar bulge of the pin was always in contact with the disk. The crevice environment area formed by the pin and disk consisted of a circle 2 mm in diameter. The crevice width could be accurately controlled by adjusting the height of the bulge on the plane of the pin. For the seamless group test, ball-disk contact was used.

Results



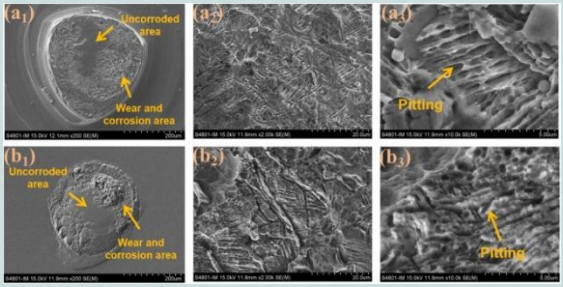
In the static corrosion test, the corrosion current was stabilized and no crevice corrosion occurred.

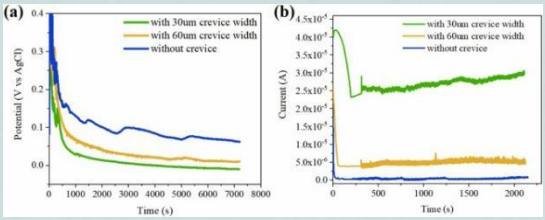
When no artificial crevice was present, the FICC phenomenon was not obvious. For tests with artificial crevices, fretting corrosion inside the crevices could easily cause crevice corrosion.

In addition, during the initial stage of material corrosion, the crevice width had no significant effect on the fretting corrosion current.

The center of the wear scar is the contact area with slight signs of wear, while the peripheral edges contained areas of severe wear.

The shear bands created during fretting preferentially corroded. The sprouting and expansion of pitting in the shear bands led to the formation of crevice corrosion, which





After corrosion pre-treatment, the fretting corrosion current was lower for the crevice-free tests. For tests containing crevices, a significant increase in fretting current was observed compared to without corrosion pretreatment.

Both fretting-initiated crevice corrosion and significant increase in fretting corrosion by corrosion pre-treatment are related to the formation of a corrosive environment within the crevice.

Conclusion

(a). When crevices were present, the phenomenon of FICC was significant. In the shear bands of the crevice interior, dense pitting corrosion initiated and expanded to the metal matrix, which led to crevice corrosion.

(b). In the presence of crevices, corrosion pre-treatment significantly increased the fretting corrosion current, thus, corrosion enhanced fretting corrosion (CEFC). The fretting corrosion current increased by 3 times and by more than 10 times with crevice widths of 30 and 60 μm, respectively (compared to before corrosion pre-treatment).

(c). The interaction between fretting corrosion and crevice corrosion was significant in the presence of crevices, compared to the no-crevice test group. In addition, the phenomena of FICC and CEFC were more significant with smaller crevice widths. Specifically, the FICC current increased steadily, and the CEFC current increased more significantl.

In vitro investigation of ESSURE type implants degradation mechanisms

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ESSURE device is a hysteroscopic sterilization system commercialized between 2002 and 2017. 750 000 women worldwide have used this method of sterilization. However, some of them have reported symptoms, such as pelvic or back pain, headache, fatigue, and loss of concentration, which led to the implant being surgically removed. Initial explant analyses show the presence of tin particles in the surrounding tissues [1,2]. Based on these observations, this study attempts to explain the corrosion degradation mechanisms that occur.

To achieve this, attention is paid to ESSURE's constitutive materials and their microstructure in order to mimic the commercial device. The latter is mainly composed of two springs, made of stainless-steel and Nitinol respectively and connected thanks to a tin/silver alloy solder. Studied samples are then formed by assembling the materials, respecting the surfaces of each one in relation to the original implant. The degradation of the samples is monitored for a six-month period in different solutions, a simplified NaCl solution and a phosphate buffered one to understand the basic reactions and a simulated uterine solution to best represent implantation conditions. The kinetics are determined by the mass loss measurements and complementary SEM analysis of the chemical composition and the morphology of the exposed surfaces and the corrosion products. The solutions are also periodically analysed to identify and measure the concentration of ions released. The analysis of the results is then discussed regarding the role of the galvanic coupling on the corrosion mechanism.

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Unveiling the effect of bovine albumin on the corrosion resistance of high nitrogen stainless steel for cardiac stents

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High nitrogen stainless steel (HNS) is deemed to be the promising alternative for traditional cardiac stents due to the combined advantages of high security, superior mechanical properties and outstanding corrosion resistance. However, only inorganic salts instead of bovine albumin (BSA) in the blood plasma were considered as the corrosive media for previous corrosion performance evaluation, whereas the bovine albumin are also vital components in the plasma which would also significantly affect the corrosion properties of HNS. Herein, the effect of bovine albumin on the corrosion performance of HNS was systematically investigated based on experimental characterization and first-principles calculation. Electrochemical measurements firstly prove that a more accelerated anodic dissolution of HNS appears in BSA contained solution in comparison with that of the ionic solution environment, which could be ascribed to the poor protectiveness of adsorbed BSA film on HNS surface together with the deterioration of the HNS passive film itself. Specifically, the defect density of the passive film of HNS has increased by two orders of magnitude from 2.29×10^{19} cm^{-3} to 4.11×10^{21} cm^{-3} in BSA contained environment, indicating the potential damage of the passive caused by BSA. By subsequent morphology and composition characterizations, it is demonstrated that BSA forms a 1.9 μm porous adsorption layer on HNS surface via the peptide bond (-CO-NH-) in a randomly curled manner. Furthermore, theoretical calculation verifies that BSA is more inclined to interact with Cr atom rather than O atom in the Cr_2O_3 passive layer, thus leading to more defects in the passive film and correspondingly resulting in the declined corrosion resistance of HNS in BSA solution. This work not only offers more deeper insights into the corrosion mechanism of HNS in simulated plasma, but also holds great fundamental basis of rational material design for future medical use.

Development of an experimental setup for determination of dissolution kinetics of bioabsorbable magnesium alloys.

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Abstract:

An experimental setup was designed and constructed in the laboratory to carry out gravimetric tests of bioabsorbable magnesium alloys. The main objective is mimic the conditions present in an incubation chamber for cell cultivation and reproduction. The assessment of dissolution kinetics is carried out under semi-static conditions, with renewed solution at an appropriate rate, compatible with the in vivo circulation rate, simulating the buffer effect present in vivo and the renewing ionic availability. The assessment conditions imposed include the presence of a controlled atmosphere containing 5% CO2, 20% O2, 37°C, 95% humidity and sterilization by UV radiation, which simulates an incubation chamber. The use of this semi-static condition setup can directly influence the formation of corrosion products and the dissolution rates of the alloys. Pre-tests were carried out to adjust operational and instrumentation parameters, and some preliminary gravimetric measurements of the alloys were performed in the presence of a simulated body fluid solution. The results obtained with the experimental setup system developed, with pure magnesium and magnesium alloys, will be complemented by carrying out surface analyses using different techniques, in order to characterize the dissolution morphology observed besides its intensity estimated by the gravimetric method.

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Friction and Wear Behavior of Selective Laser Melted Ti6Al4V-Equine Bone Nanocomposites

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Abstract

Ti6Al4V is commonly utilized in implants due to its excellent mechanical properties, corrosion resistance, and biocompatibility. Hydroxyapatite (HAp) is mainly used for solid biological fixation between an implant made of Ti6Al4V and bone tissue. However, in this study, Equine Bone (EB) was added to replace Hydroxyapatite (HAp), having a chemical structure similar to human bone tissue. Therefore, to develop an implant material with low elastic modulus, high strength, high wear resistance, and corrosion resistance, biomedical Ti6Al4V and natural Equine Bone (EB) were added, ball-milled, and then Selective Laser Melting (SLM) was used to manufacture the Ti6Al4V-0.05 EB composite. The mechanical properties, microstructure, and wear resistance, - crucial for the biocompatibility and lifespan of Ti6Al4V-0.05EB manufactured by SLM - were evaluated. Additionally, to confirm corrosion resistance in vivo, a corrosion experiment was conducted and evaluated in a liquid atmosphere similar to that of the human body.

Surface treatments of Ti alloys for biomedical applications

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Surface treatments on titanium alloys allow to tailor the surface properties of the material in order to modify wettability, improve osteointegration or allow the release of a specific drug after implantation. Among possible anodization treatments, an interesting possibility is represented by the growth on the metal substrate of titanium nanotubes, which change their morphology depending on the process parameters used during the treatment. The aim of this work is to use finite elements modelling and machine learning (ML) tools to predict the morphology of titanium nanotubes grown on titanium alloys.

In order to investigate the effect of process parameters, different sets of samples were produced using disks made of commercially pure titanium or Ti-6Al-4V alloy. After a pre-treatment in acid solution containing hydrogen peroxide, samples were washed with DI-water, sonicated in acetone for 30 minutes and then dried in air. To perform the anodization, samples were connected to a voltage source as the working electrode of the cell and a platinum electrode was used as the counter. The electrolyte was a solution containing ethylene glycol, 0.3 wt% NH_4F and 2 vol% DI water. Anodization was performed at room temperature for 4 hours, applying different values of potential between working and counter electrode.

The ML algorithm was trained using micrographs of the sample morphology taken by electron microscopy. The results showed the ability to of the ML model to predict the morphology of the titanium nanotubes, thus reducing the time needed to optimise the process parameters and correctly design the electrochemical process.

This work was supported in part by the Italian Ministry of Foreign Affairs and International Cooperation, grant number PGR02067, in the frame of the Project ‘Innovative materials and techniques for dental health (IMT4DeH)’.

Evaluating the Corrosion and Passivation Behaviour of Ti6Al4V in a Simulated Cancerous Microenvironment.

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Abstract:

Osteosarcoma (OS) is a malignant primary bone cancer, that predominantly impacts the paediatric population[1]. A Ti6Al4V internal prosthesis is typically utilised after surgical resection to restore limb functionality. However, in 4-10% of cases, localised reoccurrence of the cancer occurs[2], exposing the implant to a chronic inflammatory environment. Resultantly, oncology patients experience high Ti, Al and V ion levels[3]. The malignant environment was simulated with Dulbecco's Modified Eagle Medium (DMEM), Fetal Bovine Serum (FBS), lactic acid (LA), and hydrogen peroxide (H_2O_2) to represent the poor vascular distribution, elevated metabolic waste production and anaerobic respiration. To assess the corrosion of Ti6Al4V in the respective environments, open circuit potential (OCP) and cyclic potentiodynamic polarisation (CPP) were employed. The electrochemical properties of the passive film were investigated with the use of electrochemical impedance spectroscopy (EIS), chronoamperometry and subsequent Mott-Schottky analysis. After the specimens were exposed to the environments, x-ray photoelectron spectroscopy (XPS) was applied to evaluate the surface chemistry of the passive film. The Ti6Al4V passive film was impaired when immersed in the H_2O_2 containing medium. A 79% drop in the average film resistance value at OCP was recorded compared to DMEM + FBS + LA (98.3 vs 476 $k\Omega cm^2$). This reduction in the passive film resistance, is aligned with increase in I_{corr}, and thus corrosion rate measured in the CPP. Not only is the film less corrosive resistant, but the specimens exhibited longer time constants for repassivation. Resultantly, uncoated Ti6Al4V implants put cancer patients at an elevated risk of metal ion toxicity and thus, further development into protective coatings is required.

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Coatings based on polymeric nanofibers for titanium alloys, as anti-bio corrosive potential.

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Abstract. Titanium and its different alloys have been widely used as a material for different types of orthopedic implants due to their good biocompatibility, low density, and corrosion resistance. However, the absence of antibacterial characteristics per se and the susceptibility to bacterial colonization make it a material prone to generating infections. An infected titanium implant must be replaced, which represents a problem for healthcare systems due to the associated cost, as well as for patients since it affects their mobility and quality of life. A possible solution to this problem is to use coatings with bactericidal properties, which would prevent post-surgical infections. Furthermore, incorporating a coating into the alloy could also prevent bacteria-influenced corrosion. **Objectives.** To evaluate the combined effect of modifying the surface of Ti-13Ta-12Sn alloys with dopamine and incorporating the carvacrol-doped coating by electrospinning, to inhibit bacterial growth and its response to biocorrosion.
Results: The different characterizations by FTIR, XPS, and EDX-SEM confirmed the surface modification. Furthermore, the chemical modification of the surface allowed for improvement in the adhesion of the PCL nanofibers loaded with carvacrol. Regarding the bactericidal properties of the treated surfaces, they revealed 99.9% inhibition, and the impedance responses (EIS) suggest an inhibition of the biocorrosion process of the coated surface. **Conclusion:** The present study confirms that the preparation of coatings based on PCL and carvacrol for the Ti-13Ta-12Sn alloy inhibits bacterial colonization. On the other hand, the impedance responses suggest that these systems would also be acting as an anticorrosive barrier for the alloy under study.

Selective electrodissolution of surface asperities in additive manufactured NiCu alloy

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Abstract

NiCu alloy (alloy 400) is designed for parts subject to high thermomechanical stresses in corrosive atmospheres. Additive manufacturing is being considered for the fabrication of complex geometries [1]. However, the use laser powder bed fusion (LPBF) method result in significant surface roughness [2]. This latter must be controlled to prevent cracks formation and increase fatigue life [3]. Electropolishing (EP) treatment can effectively reduce the surface roughness by anodic dissolution of the metallic materials [4] without direct physical contact [5]. Therefore, this study investigates the selective electrodissolution for EP the surface asperities of alloy 400. Particular attention is paid on the effects of various parameters including the electrolyte composition and concentration, the applied potential, the electrolyte temperature, the agitation speed and the electropolishing time. All these conditions were firstly explored for the conventional alloy 400 prior to extrapolation to the additive manufactured one. The obtained results (open circuit potential, morphology, roughness surface, 3D surfaces topography, 2D lines) have been compared before and after EP. It was found that the roughness surface can increase or decrease depending strongly on the mechanism behind. Optimal conditions have been found with a clear reduction in surface roughness, concurrently achieving to a mirror-like (smooth, bright and homogenous) surface.

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Influence of Surface Roughness and Post-Processing on the Corrosion Properties of additive manufacturing Al6061 Alloy Produced by LPBF

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Additive manufacturing of metals is increasingly used in industry to produce complex-shaped parts. However, the surface of additively manufactured metallic parts often has high roughness (Ra > 10 µm for as produced surfaces), which can negatively impact their mechanical or corrosion resistance. To address this issue, protective coatings and post-processes such as chemical or electrochemical etching are typically needed to increase the substrate's corrosion resistance and reduce the surface roughness of additively manufactured parts respectively.

The objective of this study is to present both the influence of roughness on 6061 aluminium alloy produced by Laser Powder Bed Fusion (LPBF) and the influence of surface post-processing on corrosion properties in a neutral NaCl environment.

For this purpose, a CrVI-free conversion process was used as a protective coating, and chemical etching was used as a roughness-reduction post-processing. The surfaces have roughness values gradually ranging from Ra=10 microns for as-built surfaces to a mirror-polished surface for the least rough. The behavior of the 6061 alloy was assessed using polarization curves in 3.5% NaCl solution and the durability of the alloy was characterized by neutral salt spray test.

The open circuit potential and pitting corrosion potential were measured and discussed as a function of surface roughness and the presence or absence of CrVI-free conversion. The results showed the impact of both roughness and post-processing on the corrosion resistance and durability of the 6061 alloy.

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Corrosion morphology of 316L stainless steel manufactured by laser powder bed fusion.

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Abstract

This work investigates the corrosion morphology of AISI 316L stainless steel produced by laser powder bed fusion (L-PBF). The behavior of the as printed surface is compared with that of the bulk material to understand the effect of microstructure and roughness of the as printed surface on its corrosion behavior.

The L-PBF specimens investigated in this work were manufactured with a Concept Laser M2 Cusing machine, equipped with a 400 W single-mode CW ytterbium-doped fiber laser with emission wavelength of 1070 nm. Process parameters were optimized in order to obtain samples with very low porosity. The L-PBF stainless steel specimens were tested in the as produced condition without stress relief or recrystallization heat treatments.

A detailed characterization of the microstructure of the L-PBF 316L stainless steel samples was carried out by FE-SEM and EDXS. The as printed surface was investigated by optical microscopy and profilometry. Galvanostatic polarization measurements were carried out to evaluate the morphology of attack in 0.1M NaCl solution. After galvanostatic tests, the surface of the corroded samples was characterized by FE-SEM to highlight the higher corrosion susceptibility of the as printed surface relative to the bulk.

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Correlating corrosion behaviour of AlSi10Mg with process parameter, microstructure, defects and heat treatment

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Abstract

In recent years, there has been continuous advancement in metal additive manufacturing (MAM), allowing for the optimization of microstructure and mechanical properties, particularly in AlSi10Mg alloys. Despite several studies aimed at comprehending the mechanisms underlying microstructure formation and its impact on mechanical properties, correlations with corrosion properties remain inadequately understood. Therefore, in the present study, the corrosion performance of Laser Powder Bed Fusion (LPBF)-produced samples with different process parameters is examined, considering microstructure, defects, and post-heat treatment. Electrochemical experiments employing potentiodynamic polarization and Electrochemical Impedance Spectroscopy (EIS) are conducted in a 3.5 wt% NaCl solution to explore the influence of process parameters and applied heat treatment, reaching temperatures up to 300°C for 2 hours, on corrosion resistance. Optical and scanning electron microscopy techniques are utilized for melt pool and microstructural characterization, respectively. The results indicate that the corrosion resistance of AlSi10Mg alloy can be tailored by adjusting process parameters that control the microstructure, defect size, and morphology. Moreover, it is observed that an increase in heat treatment temperature leads to a decrease in the corrosion resistance of the produced components which can be attributed to the change in the size and morphology of Si eutectics.

Properties of Mg-Li-Ca alloys produced by laser powder bed fusion

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In the field of biodegradable materials, Mg alloys are characterised by their stiffness, which is similar to human bone tissue. This reduces the complications of stress shielding associated with bone resorption. The effect of Mg ions on bone-forming cells and their effect on bone remodelling is also beneficial. However, one of the main drawbacks limiting the broad use of Mg alloys in biomedicine is their low corrosion resistance and the associated high release of hydrogen into the surrounding environment, which causes pain in the area of implant placement [1-3]. Additive manufacturing is an attractive alternative to conventional Mg alloy fabrication, and researchers have investigated the properties of the following Mg-based alloys: Mg-Al-Zn, Mg-Zn-Zr and alloys containing REEs [4].

In this research, we develop Mg-based alloys enriched with Li and Ca. Addition of Li decreases the density of the alloys and simultaneously improve their mechanical properties. It is expected to create refined microstructure which should lead to the lowering of the intensity of the occurring corrosion mechanisms. We decided to work on the Mg-4Li-0.5Ca and Mg-8Li-0.5Ca compositions. As a reference cast materials with the same composition were used. Micro-computed tomography was used to check the porosity of the materials produced. The microstructure of the alloys was analyzed using electron back scaterred diffraction and phase composition was analyzed using X-ray diffraction. Corrosion resistance of the alloys were performed using various electrochemical techniques in phosphate-buffered saline solution (PBS). Corrosion products were characterized by FTIR spectroscopy. The materials corrosion rate was investigated by hydrogen evolution tests, and corroded specimens were characterized by SEM and optical profilometer. The results demonstrate the potential for additive manufacturing of Mg4LiCa and Mg8LiCa alloys with corrosion properties similar to their cast counterparts.

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Corrosion Behaviour of Additively Manufactured Ti-6Al-4V Parts: Effect of Surface Post-processing

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Titanium alloys are widely used across various industries due to their remarkable strength and corrosion resistance. These sectors often seek tailored components, which are challenging to produce by traditional manufacturing methods. Metal additive manufacturing (AM) offers an advanced solution for creating such components. Yet, AM parts' rough surfaces need further post-processing. Abrasive polishing (AP) is typical but not feasible for complex shapes. Electrochemical polishing (ECP) addresses this by overcoming AP tool access limitations. This study examined how abrasive polishing (AP) and electrochemical polishing (ECP) effect on the corrosion resistance of Ti-6Al-4V parts fabricated via laser powder bed fusion. Corrosion resistance was compared between: 1) as-built surfaces, 2) abrasively polished parts using SiC paper up to grade 1200, and 3) ECP treated parts at 20 V for 10 min in an electrolyte of 1 M NaCl, ethylene glycol, and 20 vol.% ethanol. Samples were tested with cyclic potentiodynamic voltammetry from -0.02 V to +6 V vs. open circuit potential in a 3.5 wt.% NaCl electrolyte. In terms of general corrosion, corrosion potentials (E_{corr}) of -231 mV (as-built), -354 mV (AP), and -286 mV (ECP) were obtained. The as-built part's corrosion current density (i_{corr}) was 0.13 µA cm^{-2}; lower than AP (0.22 µA cm^{-2}) and ECP (3.07 µA cm^{-2}) treated parts. For localized corrosion, the AP-treated part showed superior resistance, staying passive during scanning. Conversely, as-built and ECP parts revealed pitting between 4.16 and 4.24 V. This observation was supported by the voltammogram behaviour in the reverse scan, where the current density for the AP part fell below that of the forward scan, while for the as-built and ECP part, it was above the forward scan. The study reveals that as-built parts resist general corrosion better due to the natural passive oxide film, but are more prone to pitting. Among the employed post-processing methods, AP - resulting in a smoother and flat surface - showed superior corrosion properties. This study highlights how AP and ECP impact Ti-6Al-4V's corrosion behaviour. This insight aids manufacturers in selecting post-processing techniques for enhancing durability and performance of AM components.

Effect of build orientation on the corrosion behaviour of laser powder bed fusion 316L stainless steel in acidic environment

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Abstract

The need for laser powder bed fusion technology (LPBF) is increasing in the industry, so understanding the effect of the process parameters is crucial. The superior corrosion properties of LPBF parts are essential for the applications in harsh environments. 316L stainless steel samples, fabricated in various build orientations, were produced using selective laser melting (SLM). This study explores their corrosion behaviors and mechanical properties. Microstructural analyses were conducted using optical microscopy (OM), scanning electron microscopy (SEM), and X-ray diffraction (XRD). Electrochemical assessments performed in acetic acid solutions revealed that samples oriented horizontally exhibited superior corrosion resistance in the longitudinal section, likely due to pore structures and the formation of oxide films. Hardness measurements across all samples indicated that the sample with a 0° build orientation exhibited the highest hardness, highlighting significant anisotropic properties influenced by the varied build orientations.

Microstructures and corrosion properties of Ti-7.5Mo alloy manufactured by selective laser melting

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Metastable β Ti-Mo alloys, have recently received increasing attention as one of the promising alternatives to the alloy Ti-6Al-4V for biomedical implants due to their low elastic modulus and non-toxic composition. Several Ti-Mo alloys have recently been manufactured by selective laser melting (SLM) technologies, and their microstructures and mechanical properties have been investigated extensively [1-4]. However, to the best of our knowledge, their corrosion behaviour, especially in simulated body fluids, have not been reported by far. In this paper, corrosion properties of the SLM manufactured Ti-7.5Mo alloys were investigated in phosphate buffered saline (PBS) and simulated body fluid (SBF) solutions by open-circuit potential (OCP), electrochemical impedance spectroscopy (EIS), cyclic polarisation curves (PC), and Mott-Schottky techniques. The preliminary electrochemical testing results demonstrated that the SLMed Ti-7.5Mo alloys samples exhibited excellent corrosion properties with the OCPs of ca. -0.190 V vs Ag/AgCl (3.5M KCl), great corrosion resistance, especially pitting corrosion resistance. The microstructures of the Ti-7.5Mo alloy samples will also be studied with X-ray diffraction (XRD), scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDX), and X-ray photoelectron spectroscopy (XPS) to interpret their corrosion mechanisms.

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ULTRACERAMIC® PEO Refinement of Innovative Al Alloys

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Required component weight reduction often competes against wear and corrosion issues when it comes to lightweight metals. While Aluminum and its alloys are widely used in different industrial applications, e.g., aerospace, automotive and machinery, further weight reduction of components can be achieved with additively manufacturing methods of Al alloys. To overcome mechanical weaknesses, promising candidates are aluminum matrix composites (AMCs), where ceramic particles are reinforced in an aluminum matrix.

PEO is known as an environmentally friendly technique leading to highly wear and corrosion resistant surfaces on lightweight metals, but mostly applied to conventional wrought or cast alloys.

In this work we report on PEO ceramic refinement on innovative Al alloys such as Liquid Metal Printing (GROB Werke GmbH) as well as the Albolon® (AMC) material from Advanced Composite Materials Corp., which enables lightweight materials applications, where high rigidity and shape control are required.

The corrosion properties are characterized by means of electrochemical measurements and a long-term immersion test. A Pin-On-Disc tribometer test was used to analyze the wear properties of the surfaces, whereas the microstructure and the morphology of the surfaces as well as the corrosion phenomena were analyzed with the help of SEM / EDX.

The results show that the ceramic properties of these surfaces provide an extremely high wear protection accompanied by an increased protection against pitting corrosion. These promising results show that the lightweight construction potential of the innovative Al alloys can be fully unveiled by utilizing the PEO process.

KEMYA FRP Piping Network Comprehensive Strategy Study and RCM

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Introduction

The KEMYA FRP (Fiber Reinforced Plastics) network is the largest among SABIC affiliates that consists of approximately 130 km of piping, mostly underground (95%) in various water services. The FRP systems in KEMYA include Sea water system that is received by intake structure from MARAFIQ and returned to the MARAFIQ canal. Also, a takeoff from the base plant sea water return header provides make-up to a sea water cooling tower. Moreover, Firewater and potable water systems get pumped from dedicated firewater and potable water tanks, and the waste water and oily water from the units get cleaned before getting discharged back into Marafiq.

Analysis

However, the strategy studied the mechanical design of FRP network. Also, went through the susceptible damage mechanism, history of major events, current vulnerabilities and other important factors.

Conclusion

This topic will go through the details of each system by presenting scope & boundaries of the study, operating context, functions & failure modes, risk profile, and recommendation of tasks. Also, the topic will have more analysis for thrust block evaluation, and end of life evaluation for old FRP network, especially the vintage ones that was constructed since 1981.

A high-performance Mg alloy with high-strength and high-corrosion resistance designed by the model of dissolution, ionization, diffusion and deposition

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Abstract

A high-performance Mg (HPM-Mg) alloy with high-strength and high-corrosion resistance was designed based on the corrosion thermodynamics and kinetics using the model of dissolution, ionization, diffusion and deposition (DIDD) by adding various low-alloying (LA) elements and micro-alloying (MA) elements. In this work, the designed HPM-Mg (Mg-6Gd-3Y-0.5Zn-0.5Zr-0.5In) alloy was fabricated by extrusion followed by aging. The HPM-Mg alloy possessed superior mechanical properties and corrosion resistance with a yield strength of 352 MPa, tensile elongation of 15%, and corrosion rate of 0.07 mm/a in 3.5 wt.% NaCl solution. The long-period stacking ordered (LPSO) phase, refined grains, fine precipitation particles, and crystallographic texture made great contributions to mechanical strength and ductility. A dense multi-layered passive film enriched with the oxides/hydroxides of MA, LA, and Mg from the inside out was formed followed the low of downwards-magnifying effect of nucleation, contributing to the extremely high corrosion resistance of HPM-Mg alloy. This study provided a feasible design strategy for HPM-Mg alloys.

A study of the effect that added element Sn of the surface properties in ultra-high-strength steel

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Key words: automotive steel, selective oxidation, paintability, phosphopate treatment

Abstract

Many additional elements are included in steel sheets to increase the strength of steel sheets used in automobiles. Typical additional elements to increase the strength of ultra-high-strength steel sheets are Mn and Si. This additional element affects the phase transformation and structure in the steel sheet manufacturing process to increase the strength of the steel sheet. However, Mn and Si among steel sheets may be exposed to the surface of the steel sheet, which may interfere with the surface treatment of the steel sheet and cause poor appearance, depending on the oxidation layer. This affects the painting performance on automotive body for corrosion resistance. Therefore, in this study, a small amount of Tin(Sn) was added to examine the surface treatment properties and the effect of improving surface quality of ultra-high-strength steel sheets. Through this study, it was confirmed that the surface treatment properties improved with the amount of addition.

Corrosion Management Applications in Teijin Aramid: Integrating Engineering and Organizational Approaches

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This study investigates the effectiveness of an integrated corrosion management strategy that combines both engineering and organizational measures at Teijin Aramid. Teijin Aramid produces aramid yarns in harsh environments, posing a threat to the company's assets and infrastructure. The methodology employed involved the deployment of enhanced corrosion monitoring technologies, such as the development of integrated corrosion monitoring sensors and upgrading laboratory equipment, coupled with organizational improvements including better communication, documentation, and competency. The efficient communication and documentation were through an internal webpage facilitating direct interactions between corrosion experts and clients. The findings indicate that while engineering solutions are essential, organizational strategies markedly contribute to a systematic approach to corrosion management, significantly enhancing operational resilience and problem-solving efficiency. This study underscores the importance of incorporating non-engineering parameters in corrosion management frameworks, demonstrating that comprehensive strategies extending beyond traditional technical fixes are critical for prolonging infrastructure lifespan and reducing maintenance costs in harsh industrial settings.

Understanding the impact of precipitates on hydrogen trapping in Maraging steels

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In the context of the understanding of the mechanisms of hydrogen embrittlement, the influence of the microstructure on the state of hydrogen was studied. In particular, the influence of the precipitates on the solubility, the trapping and the diffusion of hydrogen was evaluated in two Maraging steels, with different chemical composition and ageing processes. The metallurgical characterization was carried to identify the nature of the precipitates (carbides or intermetallic), their fraction, their distribution and their degree of coherency. To that end, numerous techniques were used (XRD, SEM-EBSD-EDS, TEM). The materials were then charged with hydrogen electrochemically. Thus, hydrogen concentration was estimated (with TDS), and hydrogen profile through the thickness was established (with GD-EOS). Permeation was also conducted to obtain the diffusion coefficients of hydrogen for each material. Based on the results, the influence of the microstructural parameters on the distribution of hydrogen was investigated. Thus, the influence of the precipitates on the sensitivity of Maraging steels to hydrogen embrittlement was discussed.

Development and characterisation of Ni-based coatings with hydrogen barrier properties

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Hydrogen embrittlement is considered one of the main challenges to be overcome by the scientific and technological community in the next decade to properly establish and sustain the long-awaited hydrogen economy. One of the emerging and most popular approaches to tackle this issue is the use of hydrogen permeation barriers (HPB) as coating materials for metallic components, such as storage tanks or distribution pipelines. These coatings must endow a high hydrogen permeation reduction factor (PRF) to be regarded as optimal functional barriers. Although ceramic materials offer outstanding PRF values, metals can provide a more appealing commitment between PRF and mechanical properties for hydrogen storage and distribution applications.

Ni based coatings show promising hydrogen barrier properties when applied to low-alloy steels. However, the extent of contribution of the synthesis-dependent characteristics of the coatings, such as microstructure, and chemical composition, to the hydrogen barrier effect has not been explored yet. This work aimed to develop different Ni-based coatings via electroplating and electroless deposition to determine how the above-mentioned characteristics influence the PRF. Different coatings were produced to study the effect of hydrogen trapping at interfaces. Amorphous electroless-deposited Ni-P was also annealed to compare the diffusivity of hydrogen in the absence and in the presence of Ni_3P. Hydrogen diffusion parameters were extracted from Devanathan-Stachurski tests and complemented with Glow Discharge-Optical Emission Spectrometry (GD-OES) measurements. The results demonstrated that not only the thickness, but also the microstructure and the number of interlayers play a key role in the hydrogen barrier effect of the coatings.

Hydrogen mobility: testing typical alloys of a retrofitted diesel combustion engine under HP/HT gaseous hydrogen

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Abstract

The use of hydrogen as an alternative fuel to hydrocarbons for heavy transport applications is already under way. A cost-effective option involves retrofitting existing diesel internal combustion engines (ICE) to be hydrogen compatible. In this poster, we present experimental developments on the exposure of engine alloy parts to pressurized gaseous hydrogen at temperatures representative of the combustion chamber of a H_2-ICE. After exposure, mechanical analyses (micro-hardness), metallographic examinations and absorbed hydrogen measurements (thermal desorption methods) inform on hydrogen – material interactions for these materials under these environments.

2D mapping of hydrogen distribution in polycrystalline pure nickel using polyaniline coating

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As the world shifts towards carbon-free energy sources, hydrogen has emerged as a potential key player in adressing the growing demand for sustainable energy. However, the presence of dissolved hydrogen in metals can induce adverse effects on their mechanical properties, heightening vulnerability to hydrogen embrittlement. The investigation into hydrogen-metal interactions is an active and critical research area, aimed at unraveling the intricate interplay between hydrogen and materials to advance the development of safe and dependable hydrogen-based technologies. As hydrogen diffuses through the lattice, it interacts with traps such as porosities, cracks, precipitates, dislocations, etc. The understanding of microstructure-hydrogen interactions faces obstacles inherent to the challenge of detecting atomic-state hydrogen in metals Established techniques like Scanning Kelvin Probe Force Microscopy (SKPFM), Secondary Ion Mass Spectrometry (SIMS), and silver decoration methods (Ag) are well-known for achieving such observations. This study introduces a novel technique, building upon previous proposals [1,2], which involves depositing a hydrogen-ultrasensitive polyaniline coating on the surface. The devised setup includes a charging cell coupled with an inverted microscope to observe color changes on the polyaniline surface in response to hydrogen concentration variations. This setup is employed to visualize microstructure-dependent hydrogen diffusion behavior in polycrystalline Ni, shedding light on the impact of grain boundaries in hydrogen diffusion.

[1] Kakinuma H, Ajito S, Hojo T, Koyama M, Akiyama E. Real-Time Visualization of Hydrogen Distribution in Metals Using Polyaniline: An Ultrasensitive Hydrogenochromic Sensor. Adv Mater Interfaces 2022

[2] Kakinuma H, Ajito S, Hojo T, Koyama M, Akiyama E. In situ visualization of misorientation-dependent hydrogen diffusion at grain boundaries of pure polycrystalline Ni using a hydrogen video imaging system. Acta Mater 2024

Effect of Hydrogen on Mechanical Behavior of Tempered Martensitic Steels for Pressure Vessel

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Hydrogen embrittlement remains a critical concern in various industrial applications, particularly for tempered martensitic steels utilized in structural components subjected to high-pressure hydrogen environments. When hydrogen atoms permeate the steel matrix, they can be trapped at microstructural defects. The presence of hydrogen can significantly influence the mechanical behavior and properties of these steels, leading to a reduction in ductility and toughness, which are crucial properties for ensuring structural integrity and performance. Additionally, hydrogen embrittlement can promote intergranular decohesion, further weakening the material. The severity of embrittlement depends on various factors including hydrogen concentration, stress level, temperature, and steel microstructure. Experimental techniques such as slow strain-rate testing (SSRT) and fracture mechanics testing, as well as computational modeling, are usually employed to understand and predict the mechanical response of hydrogen-charged steels. Effective mitigation strategies are necessary to address hydrogen-induced embrittlement and ensure the reliability of tempered martensitic steels in demanding environments. Ongoing research aims to enhance our understanding of this phenomenon and develop robust solutions for industrial applications such as hydrogen pressure vessel and hydrogen pipelines. This presentation will provide a comprehensive overview of the effects of hydrogen on the mechanical behavior and properties of tempered martensitic steels, encompassing experimental findings, theoretical models, and practical implications.

Challenges in evaluation of components for hydrogen service

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Short presentation abstract

The transition to a hydrogen-based energy system necessitates rigorous evaluation of components designed for hydrogen service to ensure safety, reliability, and efficiency. An abundance of research on materials for hydrogen infrastructure is developed at present with a focus mainly on pipeline steels and stainless steels in order to evaluate hydrogen compatibility. But when the materials are combined in a component, such as a valve, often with a mix of metals and non-metals, it is important to consider the weakest link in the assessment of suitability for hydrogen service. The evaluation of components for hydrogen service must consider the synergistic action and interplay of hydrogen embrittlement mechanisms as well as permeation through assemblies, permissible leak rates and local stress concentrations increasing the risk of hydrogen embrittlement. The holistic approach to evaluation may even in the future allow for the use of new materials not yet deemed suitable for hydrogen service.

This short presentation will discuss the present knowledge available in assessing hydrogen compatibility of components for hydrogen service, including recent research on material susceptibility and test methods, updates on how to navigate in absence of standards and a general view on how to navigate the academic work in real life when questions arise. The lack of standardized testing protocols and the variability in performance requirements across different applications further complicate the assessment. Recent test results from FORCE Technology laboratories will be presented with a discussion on test methods and how materials research can contribute to overcoming the barriers to effective evaluation of components for hydrogen service, ultimately ensuring safe and efficient adoption of hydrogen as a key energy carrier.

Impact of Pt/Al ratios on the cyclic oxidation and TCP precipitation of β-(Ni, Pt)Al coated superalloy at 1150 ℃

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The β-(Ni, Pt)Al coating demonstrates superior oxidation resistance in high-temperature environments. Nevertheless, the interdiffusion between the coating and substrate leads to the precipitation of the topologically close-packed (TCP) phase, consequently causing a degradation in the mechanical properties of component. Therefore, comprehensive adjustment of Pt and Al concentrations was necessary to enhance the oxidation resistance of the β-(Ni, Pt)Al coating while simultaneously minimizing the occurrence of TCP phase precipitates.

It was found that oxide spallation was frequent for coatings with lower Pt/Al ratios due to the formation of fine-grained alumina and a "sandwich" structure (a multilayer porous structure) oxide scale. In contrast, coatings with higher Pt/Al ratios exhibit severe coating rumpling but superior oxidation resistance after examination. This is because the oxide scale in these coatings is mainly composed of columnar alumina grains (similar to the quasi-columnar ceramic layer in TBC) and exhibits improved deformation tolerance. In addition, higher Pt/Al also leads to more rapid replenishment of Al in the outer zone during long-time oxidation. This improves the self-healing ability of the oxide scale in these coatings after spalling or cracking. A higher Pt/Al ratio also increased the uphill diffusion of Al in (Ni, Pt)Al coatings, hindering and reducing its migration into the substrate and thereby diminishing TCP precipitation.

With an increasing Pt/Al ratio, (Ni, Pt)Al coatings display more pronounced rumpling, yet demonstrate improved resistance to oxidation. Simultaneously, the occurrence of TCP phase precipitates diminishes as the Pt/Al ratio increases.

Improving of oxidation resistance of Pt-aluminide bond coating modified by optimized Re diffusion barrier at 1200°C

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β-(Ni, Pt)Al coating exhibits excellent comprehensive performance in high-temperature oxidation resistance and hot corrosion resistance. However, the interdiffusion between the coating and substrate promotes oxidation failure. Fabricating of a diffusion barrier (DB) between coating and substrate shows remarkable effectiveness in solving the problem of coating failure. Re diffusion barrier slows down the interdiffusion rate of Al and refractory elements by creating a dense layer of stable σ phases composed of Re and refractory elements. By optimizing the Re diffusion barrier, different Re diffusion barrier modified PtAl coatings were obtained. The formation and degradation of the Re diffusion barrier and the oxidation mechanism of the coating at 1200°C were studied. The oxidation resistance was significantly improved by optimizing the Re diffusion barrier. Massive spallation and layered TGO consisting of the $NiAl_2O_4$ spinel and α-Al_2O_3 were observed in the PtAl coating due to the substantial depletion of Al by the oxidation and interdiffusion from the coating to the substrate. The optimized RePtAl coating could still maintain a dense oxide scale during oxidation, and a continuous Re diffusion barrier was formed. The Re diffusion barrier was relatively stable owing to better oxidation resistance with high residual Al.

Title: Effect of heat treatment on the tribocorrosion performance of TiAlN coating on 316L stainless steel substrate.

Abstract:

In this study, Single TiAlN coating was deposited on 316L stainless steel substrate using physical vapor deposition technique. The samples were annealed for different temperatures (500C, 600C, 700C, 800C) and characterized by scanning electron microscopy, Energy dispersive X-ray, nano-indentation testing, X-ray diffraction and 3D profilometry. The samples tribocorrosion behavior was measured by a ball on flat reciprocating tribometer in which the tribological contact was immersed in the electrolyte using 3.5% NaCl solution. The coated samples demonstrated improved wear resistance with the increase of annealing temperature. The increase of wear resistance might be associated with the formation of oxide layers at the surface between the coating and the alumina ball. All the coated samples showed a protective feature due to the ceramic structure of the coating against corrosion and tribocorrosion. And among all the annealed coated samples, the best results were achieved for annealing at 700C.

Performance of IrOx pH sensor prepared by thermal oxidation for the long term monitoring of nuclear waste disposals

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In France, Callovo-Oxfordian geological formation (Cox) has been identified to host the future deep geological disposal facility for isolation of nuclear waste in innovative reversible storage. The Cox is a water-saturated clayey environment with extremely low permeability, porosity and hydraulic conductivity. In order to monitor the evolution of the near-field around radioactive waste storage, the implementation of reliable sensors turn out to be useful to support storage safety and reversibility. pH is one of the important parameters characterizing physical, chemical, and electrochemical transformations to be monitored. This study aims to develop pH innovative all-solid-state electrodes based on Iridium Oxide (IrO_x)/Iridium (Ir). Understanding the electrochemical behavior of such metallic coatings is the key point of our research, as provides the tools for constructing and exploiting the Potential-pH abacuses, which are necessary for developing robust and reliable pH sensors. The sensors were prepared by thermal oxidation of Iridium Ir(0) at 700°C. The sensibility of electrodes was then evaluated by potentiometric measure-ments during electrode immersion in pH buffers solutions, at 25°C, under both oxic (at atmospheric pressure) and anoxic conditions (in a glove box, pN_2 = 1 atm; $pO_2 = 10^{-6}$ atm) and in the presence and the absence of sulfides. IrO_x films seem to be robust and steady on adherence and exhibit a good sensitivity, under oxic conditions (- 51 mV/pH), anoxic conditions without sulfides (- 56 mV/pH) and anoxic in the presence of sulfides (– 44 mV/pH). After thermal oxidation, the immersion of the electrodes in milliQ water for 100 days allows the hydration of the IrO_x layer, which is responsible for a decrease in $E°_{exp}$ and its stabilization at 780 mV/SHE without affecting either the sensitivity or the response time of the electrodes. XPS analyses was carried out after hydration, were shown that the Ir^{III}/Ir^{IV} redox couples are responsible for the robust pH response. Finally, the performance of IrO_x - pH sensors show their utility and ability for long-term pH monitoring.

Time-resolved Characterisation of Corrosion Processes with Hyper Spectral Imaging, LIBS and Raman Spectroscopy

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For the storage of hazardous products, corrosion processes are often linked to health & safety concerns, with the presence of higher-temperatures believed to accelerate degradation and other reaction processes. To be able to detect the very first onset of corrosion at first instance, innovative in-situ analysis and characterisation techniques need to be developed. Hyper Spectral Imaging (HSI) is a rapid and non-destructive macro-imaging technique, which enables imaging of a sample surface over a wide range of wavelengths and increments – substantially more than can be achieved with RGB components of conventional cameras. Application of HSI in corrosion detection and analysis is a fairly new field, with one of the predominant challenges being the establishment of a direct link between images and the ground truth of corrosion processes. The technique was applied to Type 316L stainless steel coupons exposed to simulated marine environment, comprising different concentrations of Na-, K-, Mg- and Ca-chlorides. Samples were exposed at room temperature and 75ºC under high humidity conditions (>90%RH) for up to 100 days. The sample surfaces containing salts and corrosion products were imaged, and then further assessed by laser confocal microscopy, Raman spectroscopy, and Laser-induced Breakdown Spectroscopy (LIBS). This study aims to explore how much information can be obtained by rapid HSI assessment of exposed coupons, focusing on: (i) presence of salt-type; (ii) identification of developed corrosion products; (iii) and to provide further insight of the effect of cation identity on corrosion. Information obtained via HSI is compared to chemical information obtained by other characterisation techniques. The application potential for HSI to remotely, non-destructively assess corrosion damage is discussed.

Predicting crevice corrosion of flange faces using recurrent neural networks and electrochemical techniques

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Bolted flanged joints are widely used in the oil and gas industry to connect pipelines, pressure vessels, and other pressure equipment. Gaskets are used between flanges of bolted joints to provide sealing. Leakage failure of these joints leads to loss of valuable resources, unexpected shutdowns, repair costs, and detrimental impacts on the environment. Crevice corrosion of flange faces is one of the most common cause of leakage failure in bolted flanged joints. As this type of corrosion degrades the flange surface from the inside of the joint, its initiation and propagation is often neither detectable nor visible. This localized corrosion spreads rapidly through a small occluded region, while the remaining surface is protected due to cathodic reaction. The corrosion process is stochastic; hence, it is not possible to determine when or where it occurs. Consequently, a periodic inspection of the joints is not useful for crevice corrosion detection before leakage failure occurs in real-world applications.

This study employs electrochemical noise measurement (ECN) as a corrosion monitoring technique to determine the propagation mechanism of crevice corrosion in an in-house test bench setup that mimics real corrosion of flanged gasketed joints. In the present study, a new approach is proposed to analyze ECN data that uses a Recurrent neural network (RNN) to classify different stages of crevice corrosion. This machine learning (ML) technique can use internal state memory to process arbitrary sequences of inputs making it applicable for analyzing time-series data, such as data obtained via ECN techniques. The electrochemical tests are performed in a 3.5 wt.% NaCl solution. The deployed gasket material is polytetrafluoroethylene, and the flange material is 321 stainless steel. The tests are conducted at temperatures of 22, 30, 40, 50, and 60^{o}C to cover the range for which the trained ML model is designed. The obtained results show that based on ECN data analysis, the RNN model is able to classify crevice corrosion with an accuracy of 92%.

High Pressure NH3 Leak Test to detect minor leakage in Urea HP Equipment

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Fatima Fertilizer Limited Multan (formerly PakArab Fertilizer) is a Urea, NP & CAN manufacturing Fertilizer complex in Multan, Pakistan, operating a unique snam progetti 300MTPD Urea plant. After about 25 years of service, minor leakage was detected in Urea HP stripper indicated by conductivity pickup of up to 96µS/cm during operation and maximum 1350µS/cm during 01 hour holdup.

Minimum limit of 1200µS/cm conductivity (operational) has been set in fertilizer industry of Paksitan as detectable due to previous experiences where NH3 leak test could not detect minor leakage and plant had to be taken in service without any work.

Despite low conductivity of 96µS/cm during operation, management decided to attend Urea HP Stripper leakage in view of significantly higher conductivity during one hour hold up. Standard NH3 leak test by NH3 pressurization up to 1.4 bar resulted in no leakage indication on NH3 sensitive paper at top and bottom tubesheets. No leakage was also detected thru NH3 developer spray application at tube to tubesheet joints and top tubes inner dia. unlined portion.

After due safety reviews and additional checks, indigenous high pressure NH3 Leak test procedure was developed to conduct NH3 leak test at progressively 3, 4.5 and 6 bar. At 06 bar, minor leakage successfully detected from 05 tubes at interface of 25.22.2 tube & zirconium liner. All relevant tubes were removed and tubesheet holes were plugged. Urea HP stripper have been in-service for 6months with no conductivity pick-up after rectification. Further testing of removed tubes revealed that leakage was attributed to accelerated corrosion in deoxygenated environment inside minor gap between 25.22.2 tube and zirconium liner.

Significance of work:

NH3 leak test at higher pressures can be utilized for early detection of minor leakages.

Glycerol as anti-corrosive lubricant for structural steel metal machining

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Glycerol, the main by-product of the biodiesel industry, is produced in excess which the industry cannot fully absorb. Therefore, a significant amount is used as a low-energy fuel, through inefficient co-incineration processes. Finding other industrial applications for glycerol could bring economic and environmental benefits. Recently, glycerol has been tested in different industrial applications, one of which is metal machining, where it has shown promising characteristics. Its high viscosity, thermal stability, and biostaticity make it a good candidate for the main petrol-based cutting fluids substitute. For this application, it is necessary to examine the anticorrosive properties of glycerol.

The low-alloy structural steel specimens (S 235 JR / EN 10025) were produced on the "Emco Compact 5" mini lathe. Carbide tooling was used without cutting fluid.

The corrosion activity of the coatings was measured by potentiodynamic polarization technique in the potential range from -1 to 1 V vs SCE, with the scan rate of 1 mV s^{-1}. The measurements were performed using a conventional three-electrode cell with platinum foil, a standard calomel electrode (SCE) and structural steel were used as the counter, reference and working electrode, respectively. The electrolytes used in the study consisted of blends of glycerol and water, with varying proportions: 0:100, 40:60, 50:50, 60:40, and 100:0.

Multidimensional Elemental and Molecular Analysis for Surface & Interface studies

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Surface and Interface corrosion studies require the use of complementary analytical techniques as each instrumentation provides results based on the interaction of the investigated material with a probing medium [1].

Obtaining elemental and molecular information for different probing size and depth are especially crucial HORIBA offers a Platform with multiple instruments able to tackle these complex analytical challenges.

Glow Discharge relies on a plasma to sputter a representative area of a material and provides fast elemental depth profile with nanometer resolution [2].

Coupling GD and Raman microscopy allows to obtain molecular information at various depths with micrometer lateral resolution [3,4].
Applying the GD software ideal to follow transient signals to a simultaneous ICP instrument coupled with an electrochemical cell (AESEC technique) offers deep insight on dissolution mechanisms and metallic surfaces performances [5].

We will illustrate the benefit of this Surface Platform for Elemental and Molecular Analysis with selected results on metallic parts for high temperature fuel cells, hard facing materials in Na fast reactors, perovskite solar cells, hydratation of anodic films and DCL coatings on bipolar plates.

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Atlas of Paint and Corrosion Defects for Offshore Gas Platforms

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Abstract

In order to reach a valuable source for a precise understanding of the causes of corrosion and paint defects, and also to mitigate the damages resulting from paint failures and corrosion damages, a comprehensive atlas was compiled based on information gathered from field visits from offshore gas platforms. This atlas could serve as a valuable resource for addressing or reducing current defects and future ones, towards economic efficiency and increasing personnel safety. It is worth mentioning that independent inspections were carried out on selected platforms in this regard. Furthermore, defects observed are based on visual inspections, thickness measurements, and field studies. In terms of corrosion conditions and paint defects, it can be stated that equipment in the lower levels of the gas platforms had suffered severe corrosion and required repairs and preventive measures. It appears that the main issues with these offshore platforms was in the splash zone. Additionally, in the windward side, the level of corrosion was significantly higher compared to other areas. In areas with insufficient access, the conditions for equipment were not suitable, and precise painting procedures need to be focused on these regions.

New approach for the design of high-temperature molten chlorides corrosion-resistant coatings

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Corrosion-resistant materials are a key parameter for the deployment of clean energy production technologies involving molten chlorides. These severe environments require materials or coating solutions capable of forming stable and protective oxide layer with a very low probability of localized corrosion. However, conventional synthesis process and corrosion testing methods used these days slow down the exploration of a wide range of candidate compositions limiting of the development of high-temperature molten salt technologies.

This work shows an integrated approach using a set of high-throughput material synthesis, microstructural characterization and corrosion testing in order to accelerate the identification of the potential composition of materials resistant to molten chlorides environments. For that, a broad range of Ni-Al coatings was elaborated by combinatorial cold spray process. Then, their corrosion resistance was evaluated in LiCl-KCl at 450 °C for 24 h.

The Ni-Al coatings presented, before corrosion as a dense and homogeneous composite. Corrosion results suggest, in addition to an influence of the composition, a strong influence of the microstructure. In order to assess the link between the composition, composite-like microstructure and corrosion behaviour these results were compared to Ni-Al coatings in solid solution.

“Corrosion of metallic materials in liquid Zn at 600°C”.

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A new concept of all-liquid Na||Zn batteries based on chloride molten salt electrolyte are being developed inside SOLSTICE project in order to achieve low cost, long life, high safety and high efficient stationary energy storage[1]. The all-liquid battery with Na and Zn liquid electrodes operates at about 600 °C with molten salt mixtures based on NaCl, $CaCl_2$ and $ZnCl_2$.

The viability of this technology relies on the selection and durability of the housing, current collector and refractory materials. The degradation of the materials has to be as low as possible when in contact with the active battery ingredients, namely liquid sodium, molten salts and liquid zinc. The behaviour of ceramics and metallic materials to be used in the housing and current collector are therefore evaluated.

In this work, the results of the corrosion behaviour in liquid Zn of selected candidate metallic materials are presented. Specifically, 316L, Ni201, Mo, Ta and W have been tested up to 1000 hours in liquid Zn at 600°C under inert gas. Large differences on the material corrosion behaviour have been observed on the different metal samples some showing stability, others degradation process like metal dissolution and intermetallic formation. The methodology followed was according the ISO 17245 Standard.

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[1] www.solstice-battery.eu

Study of the corrosion behavior of a Ni-Mo-Cr based alloy in molten NaCl – $MgCl_2$ at 600°C

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Molten salt reactors (MSR) are widely studied as next generation nuclear reactors. CEA Saclay studies in particular a MSR that would use NaCl – $MgCl_2$ – $PuCl_3$ as a coolant/fuel. One of the main challenges for its development is to find suitable structural materials that would resist corrosion in this severe environment.

Existing studies evidenced that among the conventional superalloys used in nuclear industry, Ni-Mo-Cr based ones seem to exhibit a better corrosion resistance in molten chloride salts [1, 2]. A preliminary study of the corrosion behavior of a wide number of materials in NaCl – $MgCl_2$ at 600°C confirmed this result and led to the selection of one Ni-Mo-Cr based alloy for a complete investigation of its corrosion behavior after long time immersions. In-situ electrochemical techniques (Cyclic Voltametry, Square Wave Voltametry, Electrochemical Impedance Spectroscopy) were coupled with gravimetric measurements, surface characterization (SEM, GDOES, XRD) of the material and elemental analysis (ICP-OES) of the salt to identify corrosion mechanisms.

[1] Liu et al., Solar Energy, 170 (2017), 77-86

[2] Sun et al., Solar Energy, 171 (2018), 320-329

Development of a new nickel-based alloy nano-γ' hardened and resistant to corrosion by molten chloride salts

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Molten chloride salts can be used in a large number of industrial installations, in particular as fuel fluids for new-generation nuclear reactors (Molten Salts Reactors – MSR). The structural materials used for MSR must have an excellent molten salt corrosion resistance and high mechanical properties at high temperature (between 500 and 700°C). Nickel base alloys have such characteristics, so they are often considered as structural materials for MSRs even though their corrosion resistance in molten chloride salts needs to be improved. It is therefore essential to develop nickel-based alloys that are more resistant to chloride corrosion. A new nickel-based grade for MSR is studied at CEA. The composition of this new nickel base alloy has a high molybdenum content (20 %wt.) and addition of aluminium and titanium to obtain nanometric γ' (close to Ni_3Al) precipitation.

Various corrosion experiments were carried out in a purified and qualified binary salt NaCl-$MgCl_2$ at 600°C for 168 hours. The specific mass loss of this alloy is only 0.14 mg/cm². In the same conditions, Inconel 625 has a specific mass loss of around 2.1 mg/cm².

Microstructural characterizations carried out by Small Angles X-rays Scattering (SAXS) and Atom Probe Tomography (APT) show a high density of nano- γ' in the matrix (size around 10 nm for a density close to 1.10^{23} m^{-3}).

All of these results are analyzed and discussed with respect to the objectives of developing new grades for nuclear applications.

Dual-path activation of peroxymonosulfate by S vacancies in Mo/Fe-S for antibacterial applications

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Abstract

Heterogeneous catalysts that activate peroxymonosulfate (PMS) are highly desirable in advanced oxidation process. In this study, Mo/Fe-S was synthesized from Mo/Fe-metal organic framework and used as PMS activator to inhibit bacterial growth and microbial attachment. The Mo/Fe-S material, prepared with a molar ratio of Mo:Fe=1:1 (short for Mo/Fe-S), exhibited the highest number of S vacancies (SVs) and exposed the most active sites of Mo and Fe, which were responsible for the decomposition of PMS. Confirmed by systematic characterizations and theoretical calculations, SVs in Mo/Fe-S have strong adsorption energy for PMS. $SO_4^{\cdot-}$ and ·OH are capable of damaging sulfate-reducing bacteria and *Pseudomonas aeruginosa*. At the metal sites, active species are produced through dual pathways involving the transfer of electrons in Fe(II)/Fe(III) and Mo(III)/Mo(IV). The interfacial reaction mechanism was investigated through in situ tests, and a mechanistic proposal based on vacancy catalysis and bimetallic active sites was introduced. This study provides new insights on polymetallic sulfides assisted with SVs in PMS activation for advanced oxidation processes.

Impact of marine growth and microbiologically influenced corrosion on offshore renewable energy

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Mooring chains, conventionally utilized in the oil and gas sector, also play a pivotal role in the offshore renewable energy sector, including floating wind and solar installations. Floating wind turbines give access to abundant wind resources over deep water – at least four times as much ocean surface space compared with bottom-fixed wind. These floating structures are relying on mooring systems which can be susceptible to various forms of corrosion, such as uniform, pitting, and MIC, along with marine growth. These issues can lead to material degradation, operational inefficiencies, and permanent damage to expensive assets. Therefore, in order to create reliable predictive models towards a sustainable design of floating structures, marine growth and MIC need to be taken into account. This work will provide a summary of state-of-the-art studies on mooring chain degradation, with a particular focus on marine growth and MIC. In addition, a case study from a joint industry project, where in-situ samples from seawater, biofilms, and corrosion products associated with mooring chains and their surrounding environment, will be presented. The frequent presence of corrosion-relevant microorganisms in fouling-covered mooring chain samples, indicating clear evidence of MIC processes. These findings significantly contribute to our understanding of the effect of marine growth, combined with MIC on mooring chains, addressing a critical knowledge gap in corrosion studies. This knowledge is crucial for assessing the durability of offshore renewable energy assets, particularly in the context of changing environmental conditions and climate change. By recognizing and understanding these corrosion-related risks, proactive measures can be implemented to ensure the long-term reliability and sustainability of offshore renewable energy installations.

Development of new NiMoCrAl alloys resistant to molten chloride salts corrosion

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Molten Salt Reactors (MSR) are a type of nuclear reactor working with molten salts as heat collector with nuclear fuel usually dissolved in the salts. One of the most challenging aspects for future use is to find structural materials that can withstand both corrosion in chloride salts and neutron irradiation at 600-700°C. Ni-Mo-Cr alloys seem to be good candidates to resist to molten chloride corrosion [1] as chromia (Cr_2O_3) or alumina (Al_2O_3) protective layers can improve corrosion resistance [2].

The main objective of our study is to evaluate the influence of Cr substitution by Al in a $Ni_{70}Mo_{10}Cr_{20-x}Al_x$ system on its corrosion resistance. The selection of alloys is based on microstructure, corrosion resistance and mechanical properties. Compositions of interest, produced by arc melting, are identified using CALPHAD method, characterized by SEM/EDS, XRD and hardness measurements and then immersed in NaCl-$MgCl_2$ molten salt at 600°C for one week.

SEM/EDS and XRD analyses show that in molten salt, substitution of Cr for Al promotes formation of different oxide layers composed of element such as Al, Mo, Mg, and O which reduces the mass loss of the alloy. At the same time, substitution of Cr for Al from 10%at up to 20%at triggers the precipitation of Ni_3Al and a BCC phase composed of Mo, which induces a significant increase in hardness.

The best compromise for our application could be composed of Al content between 5 and 10 %at or between 15%at and 20%at in order to limit the mass loss in corrosion and promote formation of a passive oxide layer while having controlled hardness.

[1] J. Busby & al. - technical gap assessment for materials and component integrity issues for molten salt reactors - ORNL/SPR-2019/1089

[2] Zhu & al. Solar Energy Materials & Solar Cells, 2022, 241, 111737