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**REVIEW OF MODELS TO PREDICT INTERNAL PITTING
CORROSION OF OIL AND GAS PIPELINES**

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ABSTRACT

Internal pitting corrosion is a significant factor in the degradation of pipelines used for oil and gas production. The penetration of the pipe wall by pits is a process that consists of three stages: formation of a passive layer on the steel surface, initiation of pits at localized regions on the steel surface where film breakdown occurs, and pit propagation and eventual penetration of the pipe wall. This paper reviews the various models (based on corrosion science, electrochemical science, and corrosion engineering approach) that can be used to predict internal pitting corrosion of oil and gas pipelines.

Models that have been developed based on laboratory experiments are analysed to assess the effects of experimental duration, apparatus, and conditions on the results. Electrochemical reactions are involved in all three stages. Applicability of electrochemical models to predict internal pitting corrosion of pipelines is analysed. Analysis of time-series data from oil and gas fields indicated no significant differences in superficial oil, water, and gas velocities and watercut between pipelines that had failed and those that had not. Additionally, there is no correlation of other operating parameters, such as pipe inclination, operating pressure (both maximum and average) and hydrogen sulfide (H₂S), with pit growth rates.

None of the three models cover all elements of pitting corrosion, but each one of them has a few advantages on certain aspects of pitting corrosion. A general approach to integrate the three types is outlined.

STUDIES OF OXIDATION BEHAVIOR IN TI-BASE ALLOYS

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ABSTRACT

The performance of titanium alloys depends upon oxidation resistance to atmospheric corrosion, hydrogenation and prevention processes. Oxidation is the predominant failure mode of titanium alloys, which limits use of components in gas turbine above 1073K. Resistance to oxidation in titanium alloys increases limiting temperatures. It is achieved either through bulk alloying or surface alloying. Additional alloying elements form continuous surface scales with better adherence and resistance to high temperature decomposition. Improvement in surface oxidation resistance has been accomplished by laser surface deposition/remelt, ion implantation and cementation after electro deposition and *in situ* surface synthesis. Hydrogenation embrittles metal after formation of hydride precipitation along grain boundaries or along defects of prestrain. In presence of greater niobium and hydrogen content β -phases appear to soften the metal during deformation. Other routes to improve oxidation resistance include solid freedom fabrication by laser deposition/solidification-hot working techniques, rapid solidification, powder metallurgy and foil metallurgy and directional solidification. Alternative routes to improve oxidation resistance suffer from drawback such as anomalous grain size, porosity and inhomogeneity.

**ELECTROCHEMICAL INVESTIGATION OF BARBITURATES AS
GREEN CORROSION INHIBITORS FOR MILD STEEL
PROTECTION**

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ABSTRACT

Barbituric Acid (BA), Ethyl Barbituric Acid (EBA) and 2-Thiobarbituric Acid (2-TBA) were studied as inhibitors for mild steel (MS) corrosion in 0.5 M HCl solution. Electrochemical studies were performed by means of electrochemical impedance spectroscopy (EIS) and linear polarization resistance (LPR) techniques. Inhibition efficiency of these compounds is dependent upon structure and inhibitor concentration. 2-TBA is a better inhibitor than the others. The inhibition efficiency of 2-TBA increases with increase of inhibitor concentration and reached 97.7 % at 168 hours. 2-TBA adsorbs on MS surface according to the Langmuir adsorption isotherm. The values of adsorption equilibrium constant (K_{ads}) and standard free energy of adsorption (ΔG_{ads}°) were calculated and discussed. To evaluate adsorption mechanism of inhibitor on the steel surface, the potential of zero charge (pzc) of MS was also determined by EIS method.

**REVIEW ON CORROSION PREVENTION OF COPPER USING
ULTRATHIN ORGANIC MONOLAYERS**

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ABSTRACT

Self-assembled monolayers (SAMs) are thin organic films constituted by long alkyl/aromatic chain molecules, which are chemically adsorbed with anchoring group on metal surface. SAMs modified copper has been widely studied for its corrosion resistance ability. In this short review, corrosion

protection ability of SAM modified copper substrate was discussed with some striking examples. The effect of various parameters on corrosion resistance of SAM modified copper has also been briefly explained.

CATHODIC PROTECTION WITH SACRIFICIAL ANODES.

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ABSTRACT

On the basis of the theory of bimetallic and multimetallic corrosion, the fundamentals of cathodic protection with sacrificial anodes were discussed. The exact reaction kinetic treatment of the process of this kind of cathodic protection is described. The -0.85 V and the 100 mV polarization criteria are analysed on the basis of the reaction kinetic theory described in this paper. The basic concept of sizing sacrificial anodes, including an experimental method is described. Concepts of the choice of anode materials and the role of anode beds are outlined. The chemical and physical effects (effects of oxidizing agents, organic materials, complex forming agents, catalysts, dry backfill, hydrogen embrittlement, alternating and stray current) disturbing the operation of a cathodic protection system are analysed.

The most important technological applications are also reviewed. The application of galvanic anode cathodic protection for protection of pipelines and tanks is briefly summarized. Because of the great attention devoted recently to the corrosion of reinforced concrete structures, a more detailed summary is given. Owing to its importance, a separate summary of the protection of reinforced concrete bridges has been made. Finally, a brief description of microbiologically induced corrosion in cathodic protection is given.

CORROSION OF IMPLANT METALS IN THE PRESENCE OF CELLS

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ABSTRACT

The influence of fibroblast cells on the surface composition and the polarisation and impedance behaviour of 316L stainless steel, pure Ti, and Co-Cr alloy are discussed to understand the corrosion factors in the *in vivo* environment. The characteristically precipitated elements on the surface implanted in the human body are compared with those on the surface formed in the presence of cells. The influence of cells on the chemical interface environment and the protectiveness of the passive film of the metals are examined using electrochemical techniques. The prevention of the diffusion of solutes, such as dissolved oxygen and chloride ion, by the presence of cells is then suggested. The influence of the diffusion prevention of cations (dissolved metal ions) and dissolved oxygen by the presence of cells on the pH near cells and the cathodic reaction is discussed. The difference in the influence of the presence of cells on corrosion phenomena among metals is also discussed.

**SOL GEL DERIVED ORGANIC-INORGANIC HYBRID COATING: A
NEW ERA IN CORROSION PROTECTION OF MATERIAL**

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ABSTRACT

Sol-gel derived organic-inorganic hybrid materials offer an elegant and simple material system which can be applied as an anticorrosion surface coatings. These hybrids coating material is formed through the hydrolysis and condensation of organically modified silicate with traditional alkoxide precursor. The organic part and inorganic part combined together by chemical bonds and leads to a dense, highly adherent layers and hydrophobic layer on the substrate. Sol gel derived coating material also offers the possibility of waterborne system. In this short review article, corrosion

resistance ability of these hybrid coating has been discussed with several striking example.

**COST OF CORROSION AND CORROSION MAINTENANCE
STRATEGIES**

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ABSTRACT

Corrosion of metallic structures has a significant impact on the US economy. In a recent study, the total economic impact of corrosion and corrosion control applications was estimated to be \$276 billion annually /1/ Analyses of two key sectors show that indirect (user) costs, sometimes referred to as social costs, can exceed the direct cost by a factor of 2 to 10. For the US military, the cost of corrosion has been estimated at \$10 to \$20 Billion. This paper examines the significant savings that can be realized by the application of best practice maintenance procedures.

AGEING AIRFRAMES AND CORROSION MAINTENANCE

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ABSTRACT

Ageing of structures has been deeply investigated and acknowledged as the main reason for certain accidents that happened in the late eighties. Main damage sources are corrosion and fatigue; both phenomena interact one against each other as mutual accelerating factors. To face this problem both the Federal Aviation Agency (FAA) and the Joint Aviation Authority (JAA) have established requirements for continued airworthiness. The most concerned models were old-design types, for which a systematic and comprehensive control and prevention of the corrosion was missing from the initial maintenance programme, while at the same time the fatigue behaviour of the structure was being monitored in an unsatisfactory way. ATR aircraft conform to modern design criteria regarding the damage tolerance, and their maintenance recommendations have been achieved on the basis of the MSG-

3 analysis. Little engineering activity is then foreseen to comply with such requirements, opening up the opportunity of extending the service life by 50% and therefore increasing the residual value of the entire fleet in the future. First to be developed, the Corrosion Prevention and Control Programme has been carried out since September 2002 through a series of Working Groups with the participation of many operators, authorities and ATR specialists under the supervision of the Industry Steering Committee. The results determined the revision of maintenance parameters entering the Maintenance Review Board Report like the frequency and the level of the inspections, after comparing the in-service finding data with the initial MSG-3 analysis. Assessing the damage tolerance for repairs, alterations and modifications embodied on structure permits the control of the fatigue behaviour. The Repair Assessment Programme aims at checking for condition all repairs embodied on the fleet and new maintenance recommendations are produced to make the aircraft life extension possible. The revision of the Structural Repair Manual for integrating the damage tolerance principles is also part of this programme. The Service Bulletin Review consists in identifying any suitable corrective actions that may solve potential airworthiness or structural concerns, as well as difficulties experienced during practical embodiment, connected with the inspections and modifications mandated on the in-service aircraft. The Airworthiness Limitations Review basically aims at proving the feasibility of the life extension through a new stress analysis of the Principal Structural Elements. Finally, the Widespread Fatigue Damage evaluation will check if any areas or elements exist on aircraft where the uniformity of a critical stress distribution may accelerate the simultaneous crack propagation at multiple adjacent locations and cause the residual strength of the structure to descend below the limit loads threshold. Such a structure must be either replaced or a suitable inspection programme has to be set up until the predicted structural modification point is attained. ATR reckon to achieve the Ageing Aircraft Programme for structures by the end of 2006, by means of a suitable request to the competent authority for mandating all necessary recommendations and actions.

**AIRLIFE – TOWARDS A FLEET MANAGEMENT TOOL FOR
CORROSION DAMAGE**

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ABSTRACT

The corrosion degradation of airframes occurs in a host of different environments over the lifetime of the aircraft. Most external corrosion occurs while the aircraft is on the ground or during low-level flight. Through a knowledge of the local environment including temperature, humidity, washing cycles, rain frequency and local pollution sources as well as a knowledge of how aerosols deposit onto surfaces in flight, it might be possible to determine the incremental degradation to an aircraft resulting from any particular weather event. Given this knowledge, it would then be possible to determine how (i) aircraft base location and washing cycles may change the incremental degradation, and (ii) corrosion may be reduced over the lifetime of the aircraft through appropriate maintenance. A research program has developed a tool known as Airlife, which simulates some of the environmental variables that affect corrosion development. This paper will demonstrate how the Airlife concept could be used to manage aircraft missions, base locations and refine maintenance procedures to minimize corrosion costs.

**MICROELECTRONICS & PROCESS' INNOVATION: A WAY
THROUGH COSTS REDUCTION**

Gino Esposito

SmartPoint SA President and CEO

Beyond the AIDC core technique: The use of electronic labelling in strategic context so as to draw Process Innovation and finally get cost reduction. This is the purpose of SmartPoint SA, Geneva, that, impacting on predictive maintenance management, can allow integration into existing processes to empower system and material performance.

Smart Point® is a noteworthy technological innovation for the use and management of industrial logistics. The current projects bear witness to the multi-sector versatility of the Smart Point® System. Naval, railway and aerospace industries, gas and water distribution, electrical energy distribution are just a few examples.

The SmartPoint SA's purpose, proceeding from its experience, is to open new perspectives in the traceability, asset-tracking systems in a cost-saving oriented manner. Even technology could be defined as a "shear force" support in maintenance processes' design; the Smart Point® System experience shows how predictive maintenance, physical disease monitoring activities and information infrastructure have to be integrated in supporting any effective costs reduction program and, accordingly, integrated with safety legislative requirements.

**ALTERNATIVE TECHNOLOGIES FOR CORROSION
PREVENTION – AN ANALYTICAL TOOLKIT**

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At the same time as we are attempting to improve corrosion protection in military systems we are faced with increasingly stringent environmental and health restrictions on our primary corrosion inhibitors – cadmium and hexavalent chromium. This has sparked a search for alternatives, but there

tends to be an expectation that the alternatives will never match the high performance or low cost of the originals. However, our experience with corrosion and wear resistant technologies has been the opposite – that it is possible for new technologies to improve upon the performance of the old, and to do so at substantially lower life cycle cost. This is the case because the old standbys are often not as reliable as they are assumed to be, and newer technologies are frequently far superior. The process or materials costs of the new technologies tend to be higher, but often pale in comparison with the savings that accrue from improved performance.

In looking for better alternatives it is important to think outside the box, and consider technologies that at first may not seem to be the obvious options. And when evaluating the costs and benefits it is equally important to understand how the weapons system is made and maintained, and what drives its major life cycle costs, since the most important costs may not be at all the items that come up in a typical cost-benefit analysis.

There is no one, simple way to decide on the best alternative technologies. During the course of various projects for the US DoD we have developed a suite of analytical tools that we use in assessing clean alternative technologies for corrosion and wear reduction. Technology Analysis locates the best alternative clean technologies; two new cost-benefit decision tools help us understand the most important costs and cost savings; a new Implementation Assessment approach helps us evaluate the full costs, benefits and risks of adopting new technologies, while determining the most cost-effective way of going about implementing them; while an interactive roadmapping tool shows the best route to success in complex weapons systems.

This presentation will focus on the use of these various tools, with examples of some of the more interesting and surprising conclusions that have come out of our analyses of corrosion and wear alternatives.

**INHIBITION OF MILD STEEL CORROSION IN ACIDIC MEDIA BY
AQUEOUS EXTRACTS FROM *GARCINIA KOLA* SEED**

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ABSTRACT

The inhibitive action of seed extracts of *Garcinia kola* on mild steel corrosion in 2M HCl and 1M H₂SO₄ solutions was studied using the gasometric technique. The results indicate that the extract functioned as a good inhibitor in the acidic environments and inhibition efficiency increased with concentration. Temperature studies revealed a decrease in efficiency with rise in temperature and corrosion activation energies increased in the presence of the extract. A mechanism of physical adsorption is proposed for the inhibition behaviour. Potassium iodide additives had a beneficial effect on the efficiency of the extract.

CORROSION AND HYDROGEN EMBRITTLEMENT OF THE 2024 AIRCRAFT ALUMINIUM ALLOY

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ABSTRACT

The present work aims to provide a better understanding of the effects of corrosion and the associated corrosion-induced hydrogen embrittlement on the mechanical behaviour of the 2024 aircraft aluminium alloy. Evidence is provided of the corrosion-induced hydrogen embrittlement of the material and the tensile, fatigue and damage tolerance behaviour of pre-corroded specimens are discussed under the viewpoint of a synergistic effect of corrosion and corrosion-induced hydrogen embrittlement.

The results presented rely on an extensive experimental investigation involving mechanical testing, metallographic and fractographic analyses as well as measurements of the hydrogen uptake during the corrosion process.

**COMPARATIVE STUDY OF HYDROGEN TRANSPORT
BEHAVIORS IN ARMCO-Fe AND AF1410 STEELS**

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ABSTRACT

Hydrogen is known to dissolve in steel materials with accompanying degradation of properties, and eventual materials failure. The extent of hydrogen transport effects, and eventual materials failure depends on both the nature of steel material, and its ingressing method. The study focuses on the comparative study of hydrogen transport in Armco-Fe and ultra high strength AF1410 steels. The Devanathan and Stachursky double cell (DSDC) configuration otherwise known as the permeation set-up is adopted for hydrogen charging as a function of materials thickness via cathodic polarizations in varying aqueous media. The input side cell consisted of a mixture of sulfuric acid (0.1M H₂SO₄) impregnated with 1g/l of (Na₂HAsO₄·7H₂O) sodium arsenate (as a hydrogen promoter, otherwise known as poison) after comparative tests proved it best amongst others investigated for hydrogen permeation at ambient temperatures. The input cell was powered with a potentiostat for the purpose of ensuring reproducibility between experimental runs. Based on the analyses of the permeation profiles, the coefficient of diffusion is determined to be $1.50 - 5.05 \times 10^{-8} \text{ cm}^2/\text{s}$ for the AF1410 steel and $1.39 - 2.40 \times 10^{-5} \text{ cm}^2/\text{s}$ for the Armco-Fe. Though blister formation was found to depend on charging medium, polarization current, and the thermodynamic state of the material, it was generally, substantially higher in Armco-Fe than with AF1410. Their blistering behaviors can be reconciled on the basis of their differing inherent contents and microstructural differences.

**THERMOELASTICITY FOR THE EVALUATION OF FATIGUE
BEHAVIOUR OF 6061/Al₂O₃/20p METAL MATRIX COMPOSITE
SHEETS JOINED BY FSW**

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ABSTRACT

In this study, the effect of Friction Stir Welding on a 6061 aluminium alloy reinforced with 20% of alumina particles metal matrix composite was analysed. The sheets were joined by employing a tool rotating at a speed of 700 RPM and a welding speed of 250 mm/min. Optical and scanning electron microscopy observations performed on different zones of the FSW joints cross section revealed the different nugget structures: the thermo-mechanical affected zone and the heat affected zones thanks to the difference in reinforcing particles dimensions as a consequence of the friction process. After FSW the material was aged in a 3.5% NaCl + 0.3 g/l H₂O₂ solution for 1, 10 and 90 days.

Being a non-contact technique and allowing real-time analysis unlike most investigating means used in this field, the thermoelastic stress technique was applied with success to the study of crack formation and propagation of friction stir welded MMC sheets during cyclic fatigue tests. Fatigue tests were carried out under the axial total stress-amplitude control mode with $R = \sigma_{\min} / \sigma_{\max} = 0.1$ using a resonant electro-mechanical testing machine (TESTRONICTM 50± 25 KN by RUMUL. SUI). All the mechanical tests were performed on as-FSW and aged samples up to failure. The TSA measurement system allowed crack evolution to be observed in real-time during fatigue cycles and the stress fields to be derived on the specimens directly from the measured temperature variations.

**EFFECTS OF HYDROGEN CHARGING ON AUSTENITIC ALLOYS:
A COMPARATIVE STUDY OF TYPE-321 STAINLESS STEEL AND
Fe-1.95C BINARY AUSTENITIC STEEL**

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ABSTRACT

The cold rolled AISI-321 austenitic stainless steel after prolonged cathodic polarizations in an aqueous electrolytic medium of sulfuric acid containing arsenic (V) oxide [0.1M H₂SO₄ + 1g/l As₂O₅(V)] undergoes structural transformation involving macroscopic buckling, permanent bending, and eventual tearing along the edges. Microscopically, dislocation networks, stacking faults, and martensitic phases are observed with prolonged H-charging. When compared to the charging of high Fe-C austenites, Fe-C system shows surface striations whereas none is observed with the stainless steel. While buckling and bending are also observed in Fe-C alloys, lathes-like α' -martensites are observed in stainless steel, while acicular types in the Fe-C alloys. The optimal cathodic polarization necessary to provoke structural deformation for Fe-C alloy is within 2200 A/m², while it is in the range is 50-5000 A/m² for Type-321. Mössbauer effect measurements (MEM) show that both materials decompose with retained austenite in proportion to degree of hydrogen charging, with an upper limit of 63% transformation in Fe-1.5C, while a mere 13% in the case of AISI-321. The Fe site in the formed martensites, and retained austenite are not affected by the degree or extent of the austenitic decomposition.

SOME NEW STUDIES OF SACRIFICIAL ANODES

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ABSTRACT

Several studies have focused on alloying and structural modifications of

aluminium alloy sacrificial anodes using different activators. The present work explores the effect of the addition of small quantities of the alloying element, which will not affect the basic advantages of aluminium, on electrochemical properties and homogeneity of the alloy with the commercial name Akalpro. The electrochemical characterization of aluminium anodes was carried out by observation of closed circuit potentials of sacrificial anodes sealed on steel plates and immersed in seawater. Protector achieved a stable closed circuit potential -1.173 V vs. Cu/CuSO₄ electrode, energetic capacity 2512 A h / kg and high efficiency degree of anodic material (~ 84%).

Properties of Akalpro such as the low specific weight, negative electrode potential and high current capacity and the fact that it does not sparkle when hit and does not release significant quantities of hydrogen made possible its practical applications as sacrificial anodes in ballast tanks, for transportation of oil and inflammable liquids.

CAUTION!
**HONEYCOMB CORE CAN BE DANGEROUS TO YOUR
PROGRAM'S HEALTH**

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(Disclaimer – The viewpoints offered in this paper are the author's and do not necessarily represent the views of The Boeing Company; however, they do represent 36 years of experience in the aerospace business)

ABSTRACT

Honeycomb bonded assemblies have been used extensively in aerospace because they are extremely structurally efficient, particularly in stiffness critical designs. However, honeycomb assemblies are challenging to build and some have had a rather dismal in-service record. This paper will discuss the difficulties involved in building honeycomb assemblies and will highlight some of the in-service problems experienced by both military and commercial users. Fabrication difficulties include blown core, core migration, and skin-to-core unbonds. In-service problems are usually a result of liquid water ingress into the honeycomb cells resulting in core corrosion

(aluminum core), node bond and skin-to-core degradation and occasionally, face sheet separation. Alternate design and construction concepts to honeycomb bonded assemblies will be presented, with an emphasis on integrally cocured unitized structure.

**HEALTH MONITORING OF AERONAUTICAL STRUCTURES
BASED UPON VIBRATION MEASUREMENTS AND
IDENTIFICATION ALGORITHMS**

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The purpose of this paper is to present an innovative application within the Non- Destructive Testing field based upon vibration measurements developed by the authors during these past three years at the Department of Aeronautical Engineering of the University of Naples "Federico II" (Italy). The aim of the research has been to develop a Non Destructive Test (NDT) which meets most of the mandatory requirements for effective health monitoring systems while, at the same time, reducing as much as possible the complexity of the data analysis algorithm and the experimental acquisition instrumentation.

**INCREASING THE FUNCTIONALITY OF MILITARY COATINGS
USING NANO-DIMENSIONED MATERIALS**

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ABSTRACT

The coating system presently used on military aircraft is constrained in function and limited to the use of chromate-based compounds for the mitigation of corrosion. The objective of this Multi-Disciplinary Research Initiative (MURI) is to expand the functionality of the military aerospace coating using recent advances in the materials sciences. By implementing gains in molecular and nano-engineering methods, the scientific and technological foundations will be laid for a coating that: (1) provides corrosion protection and adhesion using environmentally compliant materials, (2) senses corrosion and mechanical damage, (3) initiates mitigating responses to the sensed damage (chemical and mechanical), (4) improves fatigue resistance, (5) has the ability to change color-on-demand, and (6) provide water rejection and self-cleaning capability. The enhanced functionality of this advanced coating system will be achieved through the incorporation of: (1) a field-replaceable, nano-engineered metallic cladding, (2) the use of molecular-engineering and self-assembled colloidal crystals for packaging, sensing, color-on-demand, and super-hydrophobicity (3) the development of new approaches for the identification, encapsulation, and delivery of environmentally compliant corrosion inhibitors, and (4) the optimization of organic coating adhesion through the use of environmentally compatible surface treatments. A summary of the MURI achievements will be presented from the standpoint of time to commercial readiness.

CHARACTERISATION OF CHROMATE-FREE SURFACE PROTECTION SYSTEMS FOR AIRCRAFT APPLICATION

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ABSTRACT

Based on a combination of corrosion tests and surface analysis, a screening procedure was developed to evaluate the inhibitive efficiency of inhibitor pigments to be used in organic coatings for application on the aircraft aluminium alloy AA2024.

In addition, the influence of chromate-free inhibitor pigments on the properties of organic coatings has been investigated using a water based epoxy model primer.

SURFACE CR FREE TREATMENT FOR ALUMINIUM ALLOYS. Influence of the Conversion Layer of Surface Treatments Based on Fluorine, Titanium and Zirconium on the Corrosion Resistance and on the Surface Energy of Aluminium Alloy AA 3003 for Honeycomb Applications* .

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ABSTRACT

Lately the principal producers of honeycomb blocks are oriented to convert their production on the usage of aluminium alloy treated with chemical products free from Chromium either exavalent or trivalent.

On the other hand for environmental protection reasons, all the conversion treatments are pointing to no rinse product (with no kind of treatment of hazardous waste) which are total consumption products and they are usually applied with coil coating technologies.

In the following article there will be a complete description of the results obtained with an experimental study on surface treatments of aluminium alloys using no rinse products based on Fluorine, Titanium and Zirconium compounds supplied by Henkel Surface Technologies using samples with different conversion layer grammage: 5,2mg/m² , 10,0 mg/m² e 16,9 mg/m².

Corrosion resistance has been evaluated by using electrochemical spectroscopy of impedance (E.I.S.) in a 3,5% in weight NaCl solution inflated with air, simulating a marine environment.

The second part of the article will deal with the evaluation of the surface energy of the conversion layer by measuring the contact angle of a polar liquid (water) and not polar liquid (di-iodine methane) with an optical instrument and a mathematical interface for the data conversion.

**INVESTIGATION INTO THE CAUSE AND EFFECTS OF
WIDESPREAD COATING FAILURES AND CORROSION ON THE
INTERNAL SURFACES OF P-3 ORION WING INTEGRAL FUEL
TANKS**

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ABSTRACT

Since 2002, USN P-3 aircraft have been exhibiting signs of blistered and cracked fuel tank topcoat with varying degrees of corrosion of the aluminum structure underneath. Since the discovery, two aircraft have required wing replacement and one aircraft was scrapped. This phenomenon continues to exist today on numerous aircraft, which results in extensive additional unplanned man-hours for corrective action.

An investigation was conducted to determine the underlying cause of the coating failures. Various known causes for coating failures were evaluated and systematically rejected. The unique structure and the coating system used on the P-3 were examined and thoroughly analyzed to provide insight into the causes of the condition. The operating environment was investigated to determine the actual environment inside the fuel tanks during flight, during maintenance and during periods of non-use. Finally an evaluation was made

of the fuel itself.

It was found that the fuel contained an additive that served a dual purpose. The additive inhibits the formation of ice and it provides a biocide action. This chemical, known as DiEGME, was determined to be the root cause of the coating failures. The coating failure has been duplicated in our Materials Engineering Laboratory using DiEGME in various concentrations.

The investigation was taken one step further to determine what vendor supplied coating offered the best resistance to DiEGME. This coating will be used on the next generation of replacement wing components for the U.S. Navy's P-3 fleet.

INHIBITION OF O₂ REDUCTION ON INTERMETALLIC PARTICLES AT THE SURFACE OF AA2024 BY ADSORBED PHOSPHONATES

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ABSTRACT

Aluminum alloys are important technological materials with applications in many areas because of their light weight and high strength. However, the presence of intermetallic particles (IPs) on the surface of these alloys makes them susceptible to corrosion. We have recently shown that O₂ reduction at these IPs causes the local production of OH⁻, which etches the natural oxide layer around the IP and starts the corrosion process. In this paper we describe the adsorption of various phosphonates at the surface of AA2024 and their inhibitory effect toward the reduction of O₂. Both rotating disk and wall-jet voltammetry are used to demonstrate a reduction in O₂ cathodic current density from adsorbed phosphonates of two orders of magnitude.

Ni-W ALLOYS COATINGS AS ECOLOGICAL ALTERNATIVE FOR CHROMIUM PLATING – EVALUATION OF CORROSION BEHAVIOUR

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Among electrochemical processes having a considerable impact on technical development in a large range of industrial areas and including implications from environmental viewpoints, electrodeposition and electroforming play an important role.

Metallic layers as structures/microstructures formed through electrodeposition may be further used as final products or accurate moulds whose shapes are then copied and replicated involving sometimes again electrochemical techniques. In all cases the deposits must possess very good mechanical, thermal stability and corrosion protection characteristics. These complex performances may be especially assured when alloys of tungsten/molybdenum with iron group metals are applied that can be also electrochemically obtained as coating layers or thin metallic foils.

BORON COATING TO COMBAT CORROSION AND OXIDATION

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ABSTRACT

The present study describes the recent investigation of boronized surface coating on Steel, Ni super alloy and pure Tantalum. The coatings were produced by thermo-chemical treatment with an original technology powder mixture at the temperature range of 850-1050°C. Metallographic examination, X-ray diffraction (XRD) and microhardness testing were used to determine the characteristics of the diffusion layer compared with the substrate. The continuous weighting method and the potentiodynamic polarization measurements were used to investigate the corrosion resistance

of the specimen surface before and after boronizing. Also, the high temperature oxidation method detected by differential thermal analysis (TGA) was used to observe the oxidation resistance of unboronized and boronized specimens. It was shown that the boronizing process created a boride layer with a thickness of 10-80 μm depending on substrates, temperatures, and times, with microhardness of about 8-10 times greater than that of the substrate. The corrosion resistance of the boronized coating was determined to be 6-10 times higher than that of the substrate. As well, the oxidation resistance of the boronized coating was 3-5 times better than that of the substrate.

**THE DISCOVERY OF NON-CHROMATE CORROSION
INHIBITORS FOR AEROSPACE ALLOYS USING HIGH-
THROUGHPUT SCREENING METHODS**

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ABSTRACT

New corrosion inhibitors to replace chromate must be discovered and characterized via experimentation. One approach to accelerate the discovery and characterization process of experimentally determined products is through the use of high throughput screening (HTS) methods. This paper presents three methods for the rapid screening of potential corrosion inhibitors and their synergistic combinations for AA2024. Inhibition characteristics of 100 separate chemistries could be assessed simultaneously within hours using polarization methods along with a multiple-electrode testing system. Methods examined include DC polarization, cyclic voltammetry characterization of re-deposited copper, and fluorometric detection of Al^{3+} . Tests were conducted on single and binary combinations of the following inhibitors: cerium chloride, yttrium chloride, sodium metatungstate, sodium metavanadate, lanthanum chloride, sodium molybdate, sodium metasilicate, potassium phosphate, sodium phosphate, and barium metaborate. Testing was performed at 3.4 mM total inhibitor concentration in 0.6M NaCl. Comparison of HTS results to target electrochemical impedance

results previously acquired over 10 days of testing yielded a high correlation ($R^2=0.86$) Testing of the inhibitor combinations revealed both synergistic and antagonistic pairings. These experimental approaches provide an avenue for the rapid discovery and performance characterization of effective corrosion inhibitors in an array of conditions using combinatorial methods.

**TOWARDS REPLACEMENT OF CHROMATE INHIBITORS BY
RARE EARTH SYSTEMS**

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ABSTRACT

Rare earths as inhibitors have garnered increasing interest in recent years as replacements for chromate in deoxidizers, conversion coatings, chromate inhibited primers and repair processes. They have demonstrated performance as aqueous inhibitors for ferrous metals and aluminium alloys, as conversion coatings, deoxidizers repair processes and have been incorporated into paint systems. This paper looks at the prospects of developing a complete rare earth alternative process for aircraft applications to chromates from metal finishing to painting.

**MICROBIAL INFLUENCED CORROSION STUDIES
OF BACILLUS LICHENIFORMIS ON AA2024 ALUMINUM
ALLOYS**

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ABSTRACT

Jet fuel is frequently contaminated with microorganisms that can cause corrosion of fuel tanks. The wing tank bottom and sides are affected by the growth of a biological sludge associated with the condensed water. The behavior of AA2024 aluminum alloy in a culture of one of the principal contaminants, the bacteria *Bacillus Licheniformis* (BL), is determined. Comparative results of cyclic polarization and electrochemical impedance spectroscopy studies are presented on sterile controls and inoculated electrochemical cells. Surface changes on the alloy, influenced from the bacteria's presence, are shown from results of scanning electron microscopy with an energy dispersive system (EDS) analysis.

GALVANIC SENSOR FOR MONITORING STRUCTURAL DAMAGE

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ABSTRACT

In recent years there has been an increased research activity on aircraft health monitoring tools. Numerous studies have been carried out as a response to the demand for a better damage detection in inaccessible areas. In most of these studies, the hidden corrosion events are significantly related to the nature and magnitude of corrosive environment present in the localized hidden areas.

Because of the difficulty in accessing hidden zones and the limitations of NDE currently used, primarily corrosion damages go undetected in the hidden areas during routine maintenance inspection. For old aircraft, the accumulation with time of even weak/least corrosive environments can produce serious structural damage, as demonstrated by enormous weight loss

of material in some parts. In many critical aircraft parts the undetected corroded surfaces may lead to structural concerns acting as promoters and/or initiation sites of stress corrosion cracking and corrosion fatigue phenomena.

In an earlier effort, galvanic probes were designed and employed to measure galvanic current using electrochemical technique to monitor the corrosivity of an environment on a continuing basis in inaccessible areas. Among them, the ICS (Intelligent Corrosivity Sensor) has been the most successful application: this probe is a galvanic device that uses the condensed moisture and the environment's pollutants as an electrolyte, generating a cell current that relates to the corrosivity of the condensed film.

In the present work, a preliminary study has been done on modified ICS, to develop a probe for specifically measuring the corrosion structural part as in lap joints; i.e., probes were installed on the internal side of sandwich specimens made of Al 7075-T6 alloy. Preliminary results show that the sensor output from such tests can be used in the evaluation of hidden surface corrosion and serve as a meaningful tool to provide quite an accurate warning for subsequent inspection.

**PHM AND CORROSION CONTROL ON THE JOINT STRIKE
FIGHTER**

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ABSTRACT

The desire and need for automatic fault detection/isolation and prognostics capabilities have been around for as long as man has operated complex and expensive machinery. There has been a long history of trying to

develop and implement various degrees of Prognostics and Health Management (PHM) capability on new applications like the Joint Strike Fighter (JSF). A discussion of JSF's PHM system and its relationship to the Autonomic Logistics (AL) support concept will be presented in this paper. Overall PHM Architecture will be described with emphasis on its capabilities and its aims to enhance aircraft safety, improve Sortie Generation Rate, decrease Logistics Footprint and reduce Operation and Support costs.

In order to enable the benefits of AL support concepts, PHM will be used also for prevention, control, and monitoring of airframe and component corrosion. Corrosion control has, in the past, consisted of visual inspection, corrosion removal, and coating system repair on a regular, recurring basis. This cycle continues throughout the life of an aircraft, and it consumes a significant amount of man-hours, support costs, and material needs. Use of newer maintenance philosophies such as Reliability-Centered Maintenance, as well as introduction of corrosion prevention compounds, upgraded coating systems, and PHM, leads to a reduction in Operation and Support costs, and provides a benefit to the user in terms of reduced down time and repair requirements. Data collection, from location monitoring to tracking of inspection and repair trends, provides a key element for the continual update and refinement of a maintenance program. This paper will describe some of the innovations in aircraft maintenance practices, task interval determination, and design strategies that can be applied to JSF, and can have a positive impact to the aircraft and to the end user.

**ELECTROCHEMICAL NOISE AS A POWERFUL TOOL FOR
STUDYING CORROSION PROCESSES**

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ABSTRACT

The present work has been addressed to the evaluation of the applicability of electrochemical noise (EN) as a technique to get insights into the

mechanism of corrosion processes so as to monitor materials degradation in industrial applications. This technique can be mainly applied to the study of the breakdown of protective films or deposits at the very first moments of the process by measuring current and/or potential fluctuations originating from a two electrode system of the same material.

Accordingly, electrochemical noise was applied to study corrosion of specific materials in different testing solutions and experimental conditions. Corrosion morphology was evaluated by optical microscope while the mechanism was studied by visual examination of the EN file as well as by using statistic algorithms relating the electrochemical variables such as average noise current and potential, their standard deviations (δI or δV) and so on.

EN was successfully applied to the study of pitting corrosion of stainless steel, showing possible limitations in differentiating fast pit propagation on a small area from slow propagation of several microscopic pits on a large area.

CORROSION ASPECTS IN THE MANAGEMENT OF THE STRUCTURAL INTEGRITY OF AERMACCHI MILITARY TRAINERS

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SUMMARY

This paper, starting from some consideration about the influence on structural integrity of the fatigue design philosophy in the past decades, will provide a synthetic overview on the results of in-service inspections, tear down evidences, laboratory investigations and tests and research projects aimed at describing the corrosion prevention, inspections and control actions undertaken by Aermacchi from the first generation of MB-326 jet trainers throughout the MB-339A and the MB-339CD version up to the current final product, i.e., the fourth generation M346 trainer.

Information will be provided also with regard to the life extension programs implemented for ageing aircraft on the basis of the before mentioned in service experience, tear down inspections and laboratory tests.

**A NON-LINEAR ACOUSTIC, VIBRO-MODULATION TECHNIQUE
FOR THE DETECTION AND MONITORING OF CONTACT-TYPE
DEFECTS, INCLUDING THOSE ASSOCIATED WITH CORROSION**

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ABSTRACT

We describe an acoustic, vibro-modulation technique, based on nonlinear interaction of ultrasound and vibrations in the presence of defects, which has been developed for non-destructive detection of contact-type interfaces such as at cracks, debonding, delaminations and crevice corrosion. Low frequency vibration is employed to cause a variation in the contact area of the defect surfaces leading to modulation of a probing ultrasonic wave. Due to this effect, the spectrum of the received probe signal contains additional side-band spectral components at the combination frequencies of the ultrasound probe and vibration. Most significantly, the presence of these components allows for differentiation of the contact-type defects from other structural and material inhomogeneities. Examples of successful application of this technique include detection of stress corrosion cracks, corrosion-induced delamination of structural elements, fatigue cracks in various materials (aluminum, steel, titanium), disbonding and cracks in composite materials. Recent tests have also demonstrated that the vibro-modulation technique has a potential for assessment of aircraft lap-joint corrosion. The first prototype system of a practical instrument which utilizes the vibro-modulation technique, has been developed and tested. The system has proven to be effective for nondestructive testing of full-scale heterogeneous structures without the need to physically scan a probe over the structural components of interest.

**COATING GENERATION BY SPARK ANODIZING OF LIGHT
ALLOY**

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ABSTRACT

Findings from studies of DC anodizing of aluminium, magnesium and titanium under sparking conditions are drawn together to highlight the similarities of the anodizing behaviours and the resultant coatings. The coatings reveal characteristic surface morphologies, and usually contain amorphous and crystalline constituents, with oxides being the primary phases. Significant amounts of species derived from the anions of the electrolyte are also incorporated into the coatings. Tracer studies disclose the local formation of coating material at sites of dielectric breakdown, with new coating material being formed close to the metal, which involves short-circuiting of the prior coating layer.

ENVIRONMENTAL CONTRIBUTIONS TO FATIGUE CRACK GROWTH

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INTRODUCTION

The phenomena of crack initiation and growth kinetics in structural materials under service conditions are in general due to the combination of stress, environment and alloy chemistry. Thus the performance of a given material can be degraded by the interactive damage of cyclic loading with environment. The environment can be chemical, thermal or both. Fig. 1 is a schematic illustration (crack length, **a**, vs number of cycles **N**) of material degradation subjected to cyclic loads in an aqueous environment (like a moisture or NaCl) or in an inert (such as an ultra high vacuum) environment. Note that environment can significantly reduce the material life. If there is an under-load or overload superposed on to cyclic loads, then the life can be further degraded or improved; still remaining at a lower life with respect to

the *inert* environment. Below the service inspection limit (NDE limit), the environment can impact the early stages of crack initiation at corrosion pits or at surface scratches. These micro-cracks then grow to coalesce to a macroscopic size accelerating the growth further. It is known that there is a high probability of environmentally assisted crack initiations during the early stages of a component life. The problem of life prediction then involves the understanding and quantification of the growth of these small cracks from their initiation sites prior to the formation of macroscopically large crack. Hence the attempts in developing *reliable analytical life prediction methodology* must *unify* the crack initiation to small cracks to large cracks to final failure /1/. For comparison the US Navy (SL-safe life) and Airforce (DT-damage tolerance) design guidelines in terms of crack length are shown in FIG.1.

In the last several decades there have been several dozens of empirical life prediction models (from various countries) proposed using FEM. Lazzeri *et al.* /2/ have compared the life prediction methods from various labs for an aircraft spectrum load history under a flight-by-flight loads at a mean load of 75 MPa, for a 2024 aluminum alloy. The results are shown in Fig. 2 as **a** vs **N**. These models are basically ‘curve fitting’ models and they all tend to under predict the flights to failure of the experimental data. This under prediction probably stems from not clearly taking into account the load-load interactions. In addition, environmental effects are not included in their constitutive models. Consideration of environmental effects then would further enhance their under prediction. Inadequacies in these models are compensated by using several adjustable parameters that are obtained by correlating with lab coupon test data. Major uncertainties in predicting life come from a lack of understanding and quantifying the load-load interactions, and environmental contribution to the overall damage. As a result, to compensate for this lack of reliability in the life prediction, frequency of crack inspection is increased at many maintenance depots. In practice, vehicle safety is guarded by the use of safety factors in design, periodic NDE inspections, material quality control, etc.

In this article, we discuss the two major contributions to fatigue: service loads and environment. We present a preliminary fatigue life model based on our Unified Approach (named as *UNIGRO*), with no adjustable parameters or crack closure. We also show some examples of characterizing the environmental effects in steels and titanium alloys.

**STATISTICAL ASSESSMENT OF THE IMPACT OF INTEGRATED
DIAGNOSTIC SYSTEM ON AIRCRAFT FLEET MANAGEMENT**

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ABSTRACT

Aeronautica Militare Italiana (AMI – Italian Air Force) is getting more and more involved in humanitarian operations, aero-medical evacuations in the event of natural disaster and environmental protection. This new concept of operations defines an updated modern vision of the military force and enhances its role to serve the Nation.

Moreover, new tasks call for an improved system operational readiness, significantly greater than the traditional one related to military operations. Obviously, a war is planned, a crisis is not. Recent AMI operations have highlighted a new scenario for the deployment of air transport fleets: future years are likely to show an even more deep evolution of AMI role, during both in country and international airlift operations.

AMI managed to meet these requirements by means of a new airlift fleet and a deep organizational change into its supportability system. The present work shows that recently an actual improvement aiming at this target has been achieved, by analyzing field data collected during the management of two distinct airlift fleets over the last decade.

**CORROSION IDENTIFICATION ON AN ALUMINIUM PLATE-
LIKE STRUCTURE BY MONITORING THE WAVE PROPAGATION
PHENOMENA**

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ABSTRACT

In order to reduce the problems related to the detection of corrosion damage in aircraft structures, it is vital to develop new robust, accurate and reliable damage detection methods. A possible answer to this problem is offered by an evolution of the Non linear Elastic Wave Spectroscopy (NEWS), a wave propagation methodology developed for geophysics applications.

The NEWS damage detection based technique consists in the analysis of the frequency spectrum generated by a bi-harmonic signal. In pristine condition, the signal spectrum presents two picks at the excitation frequencies. In presence of damage, the material starts to behave non-linearly around the damage location, and this behaviour shows up in the bi-harmonic excited signal spectrum as side bands and harmonics of the excited frequencies. The magnitude and the number of the side bands and harmonics are related to damage size and magnitude. In this study, numerical findings on a welded aluminium plate-like structure are reported in order to understand the sensitivity of the NEWS technique to detect corrosion damages. The results showed that the proposed methodology appear to be highly sensitive to the presence of corrosion damage, but the methodology has yet to be developed and applied to aircraft structures and much work is needed to demonstrate the effectiveness of the methods and the ease-of-implementation in a structural health monitoring system.

**BAYESIAN ESTIMATION OF RELIABILITY FROM WEIBULL
 ACCELERATED LIFE TEST DATA**

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ABSTRACT

In several technological areas, the assessment of very high reliability levels is strongly required. In this context the high reliability level of the components under study prevents one from obtaining failure data in a reasonably short time. To face this problem, in many manufacturing industries, life tests are performed in accelerated conditions. The use of accelerated life tests makes it possible to obtain timely information about reliability.

In this paper we propose a new Bayesian estimation method for the reliability and the shape parameter of the Weibull distribution from very few accelerated life tests data. The Bayesian approach enables one to improve the efficiency of the estimation process by reinforcing experimental data with the technological knowledge that engineers possess before performing life tests.

OPTIMIZING SENSORS, SYSTEMS AND PERFORMANCE

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INTRODUCTION

When specifying/developing monitoring and prognostic systems it is important to focus on what information the system needs to deliver. One can then work backward to choose or design the optimal sensor for this task. For most metal structures this will narrow down to some form of strain, fatigue or corrosion.

Classically, the most sensitive, well-matched strain or deformation measuring system is used to collect data and corrosion is inspected manually with little (if any) correlation between what is visibly inspected and flight data being assimilated. The understanding of fatigue, and pitting in aluminum components has lead to an industry wide concentration on micro crack detection. In recent years, there has been a focus – pushed by the aero-

structural industry- to develop ever more sensitive strain gauges and sensing equipment to detect these micro cracks and the accompanying micro strain. In this paper we will propose that this focus detracts attention from what is trying to be achieved. In particular we will concentrate on the detection of changes in compliancy between sections of the structure and not the micro-cracks in each section.

If we consider a section fitted with a strain gauge or any ‘sensor’ capable of detecting micro cracking. Logically, for the system to work we have to place it over a micro crack, which infers that the precise location of where the crack will form is known. Therefore, by default, on a practical system, the logic is flawed, as at this point one would redesign. It is not unreasonable however to expect to know the general area where stress will be prevalent, e.g. the root of a wing at its intersection with the fuselage. Hence, the best that can be hoped for is to place the sensor in the proximity of where it is believed cracking would be expected to take place. There is now a high risk of reading a false negative at the onset of damage – the most critical time in the sensing process. This is because if a crack begins to form in the proximity of the sensor, it will act as a strain raiser, effectively removing or reducing the strain and hence signal that the sensor records.

It is therefore necessary to ensure that the system measures changes in compliancy or ratios of strain across the structure rather than absolute values. We shall now explain how this can be achieved effectively in parallel using a specifically designed, dual output MEMS strain gauge. The complete system operates without requiring high bandwidth, power or memory from the SHM monitoring system.

DEVELOPMENT OF A SYSTEM FOR CORROSION DIAGNOSTICS AND PROGNOSTICS

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ABSTRACT

Typically, the majority of the cost of maintaining aging aircraft structure can be associated with corrosion prevention and control. The major portion of the cost of inspecting aircraft for corrosion damage is associated with obtaining access to hidden parts of the airframe. In addition, there is the added cost associated with incidental damage that is done to the structure while gaining access to the hidden areas. There is a clear need to develop in-situ sensors and the diagnostic and prognostic algorithms to monitor corrosion environments to provide early warning of the onset of corrosion within hidden areas of aircraft.

This paper covers our proposed approach to the development of an intelligent health management system. The system is developed around the principal of network intelligence based on autonomous sensing agents (provided by a distributed agent-based network and an intelligent object-based IT platform) closely linked to multi-functional, multi-stage sensing. In principle, prognostics will be embedded in different parts of the network. This will lead to significant advantages, not least of which is a higher level of accuracy provided by network learning and the ability to respond directly to sensor input.

The system involves a multi-sensing approach and requires correlating sensor readings with actual measured corrosion (maximum pit depth). The general concept of the system will be presented, and the strong correlations found between sensed damage indicators and real surface damage for two aluminium grades (7075 and 2024) will be discussed.

AN OVERVIEW OF THE CRITICAL TECHNOLOGICAL ISSUES RELEVANT TO THE JOINING OF LIGHT ALLOYS FOR AEROSPACE APPLICATIONS

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ABSTRACT

Friction Stir Welding (FSW) is a relatively new technology that was developed at The Welding Institute (TWI) in 1991. It is a solid phase process that operates at temperatures below the melting point of the materials being joined. All aluminium alloys can be welded, including some that cannot be joined by conventional fusion techniques such as Tungsten Inert Gas (TIG). Compared to fusion welding, the relatively low temperatures involved in FSW reduce thermal stresses and distortion. There is substantial potential for employing FSW during the fabrication of various components within the aerospace, shipbuilding, and automotive industries. As these welds may experience diverse aggressive environments, it is crucial to understand the degradation characteristics. This paper looks at some of the key technological issues relevant to the joining of light alloys.

**ELECTROCHEMICAL ANALYSIS ON FRICTION STIR WELDED
AND LASER WELDED 6XXX ALUMINIUM ALLOYS T-JOINTS**

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ABSTRACT

Friction Stir Welding (FSW) and Laser Welding (LW) can be successfully employed to weld aluminium alloys, in many cases overcoming the difficulties encountered with more conventional welding processes like MIG or TIG. The corrosion resistance of the welded joint remains, however, an important issue, especially in applications (like in aircrafts), where corrosion can induce structural failure: the weld region has often lower mechanical resistance in comparison with the parent material and a decrease in its corrosion resistance, especially when the corrosion damage can represent a potential crack initiation site, can be unacceptable in components

design.

In this work the corrosion resistance of welded T-joints produced with FSW and LW on different 6xxx aluminium alloys is investigated. These alloys offer good mechanical properties and high corrosion resistance and are often used in aircraft fuselage components. Processes like FSW or LW, however, can induce, in age-hardenable alloys like the 6xxx ones, significant metallurgical modifications and consequent changes in the electrochemical reactivity.

This work proves that, if the alloys and the welding parameters are chosen correctly, for both FSW and LW it is possible to obtain welded joints such that galvanic couple established between the welded region and the parent material results in preferential attack of the latter: this drives corrosion away from the weld region and reduces the cathode/anode area ratio, improving the corrosion performance of the whole weld.

THE INFLUENCE OF TARTARIC ACID ADDITIONS ON THE ANODIZING BEHAVIOUR OF AA2024-T3 ALLOY IN SULPHURIC ACID

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ABSTRACT

AA2024-T3 Al alloy was anodized in a 0.46 M sulphuric acid solution and in a potential alternative sulphuric (0,46M) + tartaric (0,53M) acid solution. The anodising process was carried out in both solutions at constant voltage, following an Alenia S.p.a Patent. The Al alloy was pre-treated by etching in NaOH at 40°C, and desmutting in 0.3 % vol HNO₃ at room temperature. The morphologies of the anodic films generated in the selected anodising solutions were examined by TEM and FEG-SEM: the electrochemical behaviour of the anodised 2024-T3 alloys was investigated using DC and AC electrochemical techniques. AC measurements were performed in 0.6 M NaCl, and 0.5 M Na₂.SO₄, and 0,1M NH₄B₅O₈4H₂O

solutions, while DC measurements were carried out in 0.46 M sulphuric acid and in 0.46 M sulphuric + 0.53 M tartaric acid solutions at room temperature.

The FEG-SEM probing of the as received alloy revealed rolling lines and the presence of second phase particles; after anodizing, the porous film morphology was readily revealed at the surface of the anodic film. Transmission electron microscopy of ultramicrotomed sections of the as received AA2024-T3 alloy revealed the presence of relatively thin disturbed layer of fine-grained alloy. TEM observations of the anodic films, showed a porous layer of about 1400 nm thickness for both anodising conditions and relatively thin barrier layer thicknesses of 17.2 and 23 nm for films formed in sulphuric and in the mixed acid solutions respectively.

Results obtained by d.c. measurements indicated that the electrochemical behaviour of the anodized alloy is dominated by the acid content of the test solution rather than by its structure. Data obtained by EIS in 0.1 M $\text{NH}_4\text{B}_5\text{O}_8\text{H}_2\text{O}$ at high frequencies, showed a slightly more capacitive behaviour of the film formed in the mixed acid solution. EIS data obtained at low frequencies (0.01 – 1 Hz) exhibited a marked difference in the phase angle plot that was attributed to a more porous morphology of the anodic film formed in sulphuric + tartaric acid solution.

PREVENTATIVE MAINTENANCE AND FAILURE ANALYSIS OF AIRCRAFT COMPONENTS

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ABSTRACT

More than 10 years ago, the three major causes of failures in the Israel Air Force were: maintenance (~16% of failures), manufacturing (~14%), and

design (~12%). While fatigue (~34%) and overload (~23%) were the two major failure mechanisms, more than 10% of failures were related to corrosion mechanisms. These include stress corrosion cracking, corrosion fatigue, localized corrosion, hot corrosion, uniform corrosion, *etc.* In this presentation, we provide several definitions of important terms related to failure analysis, present a recommended failure analysis protocol, and summarize several case studies of aircraft components that failed due to corrosion-involving mechanisms.

Implementation of routine condition monitoring techniques (such as ferrography) and failure analysis protocols is valuable in preventing failure recurrence. Ferrography is a method for particles isolation on a glass slide, based upon the interaction between an external magnetic field and the magnetic moments of the particles suspended in a flow stream. By quantifying the number and size of captured particles and determining their chemical composition, shape and surface morphology, the origin, mechanism and level of wear may be determined. Here, we briefly review the application of ferrography in monitoring the health of aircraft assemblies.

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CORROSION INHIBITION POTENTIAL OF SULFADIMIDINE

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ABSTRACT

Corrosion inhibition of mild steel (MS) in 1M hydrochloric acid (HCl) medium and 1M sulfuric acid (H₂SO₄) medium by sulfadimidine (SDE) have been studied by weight loss method, electrochemical measurements, SEM and quantum chemical studies. The weight loss studies were conducted at different temperatures (30°C, 40°C, 50°C & 60°C) using various concentrations of SDE (0,25,50, 100, 150,200,250,300,400 & 500ppm) and at two time intervals (1h and2h). Inhibition efficiency was found to increase

with increasing SDE concentration. It is found that SDE produces corrosion inhibition through adsorption obeying Temkin's adsorption isotherm. The ΔG_{ads} values reveal the type of adsorption to be physisorption. The E_a values for corrosion process determined using Arrhenius equation also support this. The recorded polarization data showed that the corrosion resistance was greatly enhanced in the presence of increasing SDE concentrations which was complimented by impedance measurements. SDE acts as anodic type of inhibitor. Surface examination using SEM revealed the protection efficiency of SDE which was complimented by quantum studies.

CATALYTIC ASPECTS OF OXYGEN REDUCTION IN METAL CORROSION

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ABSTRACT

The most important cathodic process of metal corrosion is oxygen reduction. This process, however, is a complicated multistep catalytic process. A well known catalytic oxygen activator is the acidic $\text{Fe}^{3+}/\text{Fe}^{2+}$ redox system. In the case of rusting iron the Fe^{2+} ion containing lepidocrocite is the catalytic activator of oxygen. There are many metal complexes capable of oxygen activation. They can help increasing metal corrosion rate.

A COMPARATIVE STUDY OF INHIBITIVE EFFECTS OF SOME SCHIFF'S BASES ON MILD STEEL IN ACID MEDIA

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ABSTRACT

Mass loss, thermometric and scanning electron microscopic (SEM) techniques have been employed to study the corrosion inhibitory effects of some newly synthesised Schiff's bases viz. N – (furfurilidine) – 4 – methoxy aniline (SB₁), N-(furfurilidine) – 4 – methylaniline (SB₂), N-(salicylidine) – 4- methoxy aniline (SB₃), N – (cinnamalidine) – 4 – methoxy aniline (SB₄) and N-(cinnamalidine) – 2 – methylaniline (SB₅) for mild steel in HCl and H₂SO₄ solutions. Results of inhibition efficiencies from all the three techniques show that Schiff's bases are good inhibitors in both the solutions. Inhibition efficiencies increase with increase in the concentrations of acids as well as those of inhibitors. Maximum efficiency for H₂SO₄ was found 97.01% whereas for HCl it was found 97.93%. It was also found that all the three techniques show good agreement with each other.

EVALUATION OF MARINE BACTERIA BIOCORROSION IN A DYNAMIC SYSTEM IN THE PRESENCE OF LEAD

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ABSTRACT

Various species of microbes present in marine environments are responsible for the corrosion of metals. The objectives of this work were to analyze both the growth of some marine microorganisms in the presence of Pb, and biocorrosion in a dynamic system. Carbon steel AISI 1020 coupons were inserted in a PVC ("loop") system, with the goal of simulating natural conditions, and exposed to seawater, using lead concentrations of 25 to 50 ppm. For fifteen days, the planktonic and sessile populations— aerobic, anaerobic, and sulfate-reducing bacteria (SRB)—were quantified through the MPN technique. The corrosion rate was determined by the weight loss of the coupon. The coupons were also microscopically analyzed, and the percentage pit/cm² was determined using the GLOBAL Lab IMAGE Program. The resistance of the planktonic bacteria to the Pb was dependent upon the

bacterial group. The SRB were more sensitive to the presence of lead, demonstrating mortality proportional to the metal concentration. After 15 days, a larger number of sessile bacteria was determined on the biofilm exposed to 25 ppm of Pb, and a reduction of the number of cells in 50 ppm, especially for the SRB. The corrosion rate of the coupons exposed to 25 ppm of Pb was elevated, much higher than that of those exposed to 50 ppm. The percentage pits/cm² was 5.64 and 2.66, respectively, for 25 and 50 ppm of lead. These results suggest that the rise in lead concentration inhibited the growth of SRB, and the corrosion was directly affected by the activity of the SRB.

PREPARATION AND OXIDATION OF AN Y₂O₃-MODIFIED CHROMIZING COATING

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ABSTRACT

An Y₂O₃-modified chromizing coating was produced by chromizing an as-electrodeposited Ni-Y₂O₃ composite film using pack cementation method at 1100°C for 3hr. For comparison, chromizing was also performed in the same condition on an as-deposited Ni film without Y₂O₃ particles. Oxidation at 900°C for 120hr showed that compared to the Y₂O₃-free chromizing coating, the Y₂O₃-modified chromizing coating exhibited a superior oxidation resistance. The effect of Y₂O₃ on the chromization and oxidation of the chromizing coating is discussed in detail.

CORROSION OF TITANIUM BIOMATERIALS, MECHANISMS, EFFECTS AND MODELISATION

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ABSTRACT

The *in vitro* and *in vivo* research results show very low corrosion rate of Ti bioalloys. Among different sources of corrosion, the general and localized corrosion *in vitro* and fretting corrosion *in vivo* are the most expected degradation processes. Three possible mechanisms of dissolution of Ti biomaterials include: dissolution of titania layer, diffusion of elements through the oxide layer, electrochemical reaction in corrosive environment of the bare metal inside the damaged layer. The corrosion processes result in deterioration of human body by corrosion products followed by loosening of implant and possible serious diseases. The standard research techniques are inadequate as regards the assessment of long-term corrosion, localized corrosion of porous materials and dissolution of oxide layer. The further research is necessary to estimate the critical steps allowing for metals dissolution and optimization by physical modelisation and treatment by mathematical techniques, especially fuzzy logic and neural networks.