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AUTOMOTIVE CORROSION Symposium

SPEAKERS & ABSTRACTS

Automotive Corrosion Symposium

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New Corrosion Prevention Technologies

Exploring the Possibility of Adding Fire Preventative Capabilities to our Automotive Corrosion Preventative Coatings
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Plasma Electrolytic Oxidation Coatings on Light Alloys for Automotive Applications: Properties, Performance, and Prospects
Vahid Dehnavi, Sridhar Ramamurthy, Jeffrey D. Henderson, Mohammad Norouzi Banis, David W. Shoesmith, and Jamie Noel (The University of Western Ontario)

Development of Accelerated Corrosion Test Methods Using Wet-Dry Cycling of Varying Salt Solutions and the Study of Coating Damage Evolution via Electrochemical Test Methods

Victor Ponce, Shaik Merkatur Hakim Marjuban, and Homero Castaneda (Texas A&M University)
Heather Eich, Allison Mahood, and Rishi Gupta (Toyota Motors, North America)

Wet-dry cyclic testing has been used to accelerate corrosion failure mechanisms by exposure to harsh conditions in a controlled laboratory environment. The stress parameters in the cycling environment include temperature, salt composition, and humidity, in an effort to replicate real-world conditions while increasing the degradation rate. With the current accelerated methodology, corrosion is characterized by visual analysis. This work studies the characterization of automotive coating/substrate systems after exposure to an accelerated corrosion environment via electrochemical testing, mechanistic analysis, and mathematical framework. The methodology included different temperatures, salt compositions, and monitoring setups.

The cycling process included a wet condition, with four days (96 hours), and a dry condition lasting three days (72 hours), completing a 1-week cycle. Corrosion testing was conducted using a Cyclic Corrosion Test (CCT) chamber with varying solutions including NaCl, $CaCl_2$, and $MgCl_2$. Three distinct coating types with different corrosion control mechanisms were studied.

Electrochemical assessments were conducted in real time via electrochemical impedance spectroscopy (EIS) to quantify different degradation stages. The phase angle data was analyzed over 30 days of exposure and provided valuable insights into the corrosion mechanisms based on the damage evolution stages previously developed using steady-state methods. The phase angle plots from EIS were also utilized to monitor and quantify the state of the coating and substrate surface during steady-state conditions and train an Artificial Neural Network (ANN) as an arrangement of Time Series Prediction (TSP). The ANN has predicted the coating performance for several years, and the experimental results have been validated by scanning electron microscopy (SEM) imaging of cross-sectioned samples.

These findings underscore the importance of accelerating protocol to simulate field conditions and supported the development of new accelerated corrosion testing methods to quantify corrosion performance using damage evolution modeling.

Laboratory Corrosion Tests: Correlating the Delivered Volume of Electrolyte with Corrosivity

Sean Fowler (Q-Lab Corporation)

Automotive corrosion test methods use a variety of electrolytic solutions and application techniques. Typically, the recipe for the solution is precisely defined in the relevant standards, and sodium chloride is almost universally included in the various recipes in concentrations ranging from 500 ppm to 5%. Sometimes, other salts are added, and sometimes the solution is acidified. Unfortunately, the application technique employed is not defined as clearly. The term "salt spray" is used for two different techniques, often causing confusion. This presentation will propose standardized terminology to define the two types as fog and shower.

Controlling the volume of salt solution spray is usually considered a critical factor for repeatability and reproducibility. When using the fog type of spray, the volume is typically well-defined using a long established measurement technique. The volume of the shower type of spray is defined in some cases, but not always. How important is it to quantify this value? This presentation will show data comparing corrosion rates of steel panels as a function of the shower volume in an attempt to answer this question.

Effect of RH Cycling on Scribe Creep of Coated Steel Panels

James F. Dante (Southwest Research Institute) • Pedro Atz Dick (PPG)

It is well known that Time of Wetness (TOW) strongly affects the degree of corrosion and scribe creep. During accelerated corrosion testing, TOW is often controlled by the salt fog/spray application time. In outdoor environments, TOW can be caused by splash, precipitation events, and the time that the RH exceeds 75% RH (the deliquescence RH of NaCl). Recent work has demonstrated the importance of RH cycling on corrosion morphology. For coatings, RH values below the DRH often result in enhanced coating delamination. Coating delamination and scribe creep are close related. In this work, scribe creep was measured as a function of various cyclic RH conditions for two different coating systems. Coating performance after 28 and 56 days are compared in each environment. The relationship between scribe creep, cyclic RH, salt spray application, and TOW are explored. The data reveals that a linear relationship exists between TOW from RH cycling and scribe creep. However, TOW during RH cycling cannot account for all scribe creep observed. Additionally, significant differences in relative coating performance are observed after 28 and 56 days of exposure. These differences are likely the result of a multistep process responsible for scribe creep.

The Use of Corrosion and Environmental Sensors in Automotive Test Environments

Danyil Kovalov • Jacob Meisberger • Niamh Hosking (Ford Motor Company)

Corrosion and environmental sensors produced by Luna Labs were deployed in laboratory corrosion test chambers and on-vehicle at Michigan Proving Ground for real-time measurement of corrosion rates and the concurrent environmental conditions. The sensors incorporated active surfaces for the measurement of a free corrosion rate for aluminium alloy AA6111 in the uncoated condition, and a galvanic current for uncoated AA6111 coupled with uncoated steel. A high frequency (25kHz) impedance measurement across the gold interdigitated electrode, incorporated in the sensor was used to quantify the resistance of electrolyte formed on the sensor surface. The sensors also recorded air temperature, surface temperature, and relative humidity during the exposure period. Data was collected over a 2-week period in the test chambers, and over a 4-week period on the test vehicle.

Incorporation of Digital Design Tools for Corrosion and Corrosion Protection

Initiating Corrosion Prevention During the Design Phase: Utilizing Computer Aided Analysis to evaluate Corrosion Risks During Material Selection

Aga Franczak (Elsyca)

In the age of new metallic materials development, which is strongly demanded by the automotive industry, the effectiveness of the proper materials selection is a major challenge, as a corrosion engineer is not usually involved in the early stages of the component design. The design validation activities are mainly focused on Finite Element Analysis (FEA) regarding the structural performance of the materials and flow simulations for the casting process. The corrosion resistance analysis is often overlooked or is not given the required priority, which can result in a design modification or a complete redesign if the component will not pass the final corrosion testing. This implies a significant time, cost and schedule impact on the entire product delivery. Hence, a systematic investigation of the materials compatibility needs to be undertaken already at the design stage. In this context, Computer Aided Analysis (CAA) delivers a fast and robust qualitative analysis of the potential corrosion risks on mixed multi-material 3D computer models. The predictive modeling approach employs an FEA method

to solve the fundamental electrochemical equations that govern the corrosion phenomena. The simulation results provide information on the corrosion intensity that in terms of numerical simulation methods, should be predominately considered in terms of qualitative information. Nevertheless, computer modelling provides a great opportunity to associate corrosion risks already at the design stage, permitting to implement proper mitigation strategies long before the actual component is manufactured and begins its service life.

A Computational Strategy for Corrosion Mitigation and Prevention

Julio Mendez, Siva Palani, Alan Rose and Keith Legg (Corrdesa LLC)

In the automotive and transportation field, the accurate prediction and effective management of corrosion risks play a pivotal role in ensuring the longevity and safety of critical components. Presently, the predominant methods for characterizing corrosion processes and understanding failure mechanisms primarily rely on established techniques, including full-scale experiments and accelerated tests such as ASTM B117 Salt Spray and Salt Fog Testing. However, these conventional methods come with significant drawbacks, including lengthy testing durations and challenges associated with replicating the intricate conditions encountered in diverse applications. Additionally, the evaluation of materials combinations, surface treatments, coatings, and other corrosion mitigation strategies often entails substantial costs. Consequently, the final recommendations are often constrained by the limited combinations assessed during the initial engineering phase of the design. Fortunately, with the advent of powerful computing resources, coupled with extensive and robust databases, we find ourselves on the cusp of a transformative era where computational methodologies are taking center stage. Among these approaches, Computational Fluid Dynamics (CFD) has emerged as a potent tool capable of linking digital representation of systems, parts etc. to corrosion rates in various configurations, such as stack-up coatings, down-hole applications, and geometric configurations commonly encountered in the automotive sector.

This work introduces a novel set of computational workflows specifically tailored to address analyses spanning multiple levels of complexity and fidelity. Central to these workflows is the utilization of a unique source of truth—an electrochemical database derived from Appendix B of the MIL-STD-889D. Leveraging these advanced computational tools facilitates the efficient integration of the digital thread in automotive applications. By augmenting existing digital twins with CFD data that represents corrosion control and prediction, this approach significantly enhances the entire design cycle and maintenance processes.

In summary, as computational approaches gain momentum, they offer a transformative solution to the challenges associated with traditional corrosion testing and prediction methods. The incorporation of CFD-based analyses, underpinned by a comprehensive electrochemical database, empowers the automotive industry to embrace a digital-driven approach that not only enhances design precision but also contributes to the seamless management of corrosion-related concerns throughout the lifecycle of critical components.

Enhancing Corrosion Resistance in Multimaterial Joints for Automotive Lightweighting Applications

Sridhar Niverty, Rajib Kalsar, Yucheng Fu, Alasdair Crawford, Vilayanur V. Viswanathan, Benjamin J. Schuessler, and Vineet V. Joshi (Pacific Northwest National Laboratory)

The widespread adoption of lightweight materials, such as magnesium (Mg) and aluminum (Al) alloys, in automotive design introduces new challenges related to corrosion. This stems from the distinctive corrosion behaviors of these materials and the prevalence of multimaterial joints, which can lead to localized galvanic and crevice corrosion in automotive environments. In this comprehensive study, we employ Multiphysics COMSOL simulations and mathematical modeling to systematically analyze and rank geometric factors affecting galvanic corrosion in multimaterial joints, such as area ratio (cathode to anode area ratio), anode size, rivet geometry, etc. Furthermore, our investigation extends to modeling the impact of surface modifications, such as plasma treatment and adhesive use, on galvanic corrosion in multimaterial joints fabricated through High Velocity Riveting (HiVe). Guided by the modeling insights, we design and conduct extensive corrosion experiments, exploring the initiation and progression of corrosion over durations of up to 1400 hours under salt fog (ASTM B117) and simple immersion conditions.

The combination of modeling and experimental results underscores the pivotal role of the area ratio and the influence of surface treatment on corrosion initiation and progression. Gravimetric analysis, electron microscopy, and 3D time-resolved x-ray tomography collectively demonstrate that adhesives and surface plasma treatment effectively reduce susceptibility to corrosion between faying surfaces. Notably, our findings indicate that, where applicable, rivet-less HiVe joining emerges as the most effective strategy to mitigate corrosion in multimaterial joints. This research contributes valuable insights to the ongoing pursuit of corrosion-resistant lightweight materials in automotive engineering.

Developing Digital Tools for Prediction of Galvanic Corrosion in Mixed Materials

Siva Palani, Vinod Upadhyay, Amber Young (Corrdesa LLC) • Niamh Hosking (Ford Motor Company)
Ullrich Haus (General Motors Company)

Increased use of dissimilar materials (metal/coated alloys) for purposes of strengthening and lightweighting of vehicle structures necessitates understanding of the galvanic compatibility between the mixed couples. Determining the possibility of coupling such material may involve a lengthy corrosion testing process using traditional exposure tests approved by individual OEMs, and/or electrochemical measurements under a suitable environment. A digital tool for the galvanic corrosion prediction of mixed materials would therefore aid the engineers during design verification, increase efficiency and robustness of design reviews, and at the same time reduce reliance on new physical testing if information already exists. To address this gap the goal of this work is to develop a digital platform that can aid in the galvanic corrosion assessment of vehicles designs in CAD. A set of relevant electrochemical data for automotive construction materials will be generated. These data will then be added to the galvanic corrosion prediction tool, integrated with Siemens PLM environment. This will be followed by classification of galvanic corrosion risks in the automotive CAD environment based on measured data.

Using Virtual Tools in Corrosion Design for High-Performance, Low-Cost Vehicles

Elliot Smith (General Motors Company)

Vehicle corrosion performance has improved over time as customer expectations have grown. Owners expect their cars to last longer, with greater reliability and performance. Advancements have been made in the design phase to meet evolving customer expectations, ensuring corrosion robust designs, E-coat coverage, and proper material selection. This presentation shows how corrosion mitigation strategies, virtual tools, and previous vehicle level testing are all being used to design vehicles while maintaining the lowest possible cost, and boosting manufacturing efficiencies.

Corrosion Avoidance in Automotive High Voltage Battery Enclosures

Eric Romanowski (General Motors Company)

Corrosion protection for high voltage battery enclosures is crucial to ensure the longevity and reliability of electric vehicles and energy storage systems. This abstract explores various corrosion prevention strategies employed in the design and manufacturing of high voltage battery enclosures. The abstract also highlights coating technologies, material selection, and advanced engineering solutions aimed at mitigating corrosion risks.

Road Exposure Corrosion Evaluation of Aluminum Alloys for Automotive Applications

Ganesh Bhaskaran, Kevin Ryan, Yudie Yuan, Shanshan Wang, John Ho, and Mary Lyn Lim (Novelis)

Aluminum sheet products offer higher specific strength than advanced high strength steels, making them a preferred material of choice for automotive lightweighting. Corrosion resistance is one of the key requirements of automotive customers. To truly understand the "in-service" corrosion behavior of the aluminum alloys, Novelis has completed a two-year in-service road exposure evaluation. Automotive grade 6XXX and 7xxx materials with a variety of scribed panels and lap shear joints were fastened to a truck trailer and exposed to the harsh Canadian environment(s), traveling over 360,000 km in the process. These results, along with outcome from Novelis' future testing will provide invaluable feedback to our automotive customers and reinforce the value-in-use of aluminum for the automotive market.

Real-Time Performance Measurements for Electrocoat Primer and Powder Coatings

Victoria Avance (Luna Labs)

The first line of defense and the single most important factor in controlling corrosion of vehicles is the protective coating system. E-coat and powder coatings have been utilized by the automotive industry for decades, have minimal heavy metals or volatile organic compounds, and are very efficient for factory-applied coating processes. However, as optimized coatings are developed for increased corrosion protection, it often takes 10 – 20 years for adoption in automotive and aerospace industries, in part, because of the lack of confidence in performance testing. The purpose of this work is to adapt existing coating performance measurement techniques and test instrumentation used for the characterization of spray-applied liquid coatings to obtain more rapid and accurate coating performance metrics in laboratory tests, outdoor exposures, and test vehicle evaluations. These test and measurement capabilities will improve the development of new coatings and characterization of material combinations to reduce the time to market and associated corrosion risk.

In this work, a prototype multichannel ZRA system was used to continuously monitor sample assemblies composed of aluminum, steel, and carbon fiber reinforced polymer composite with various coating systems in accelerated corrosion and outdoor conditions. The sample design is derived from those common to the automotive industry. They consist of a base panel with an E-coat, or powder-coat, and a cover sheet that is galvanically coupled to the base panel. Inert polymer spacers are placed between the two materials to create a crevice with controlled gap dimensions. A coating defect can be created either by masking before coating or mechanically scribing after coating. The ZRA device enables continuous galvanic corrosion measurements on up to eight sample assemblies. A description of the samples, electrochemical measurement device, and methods for coating testing will be reported along with the analysis of the resulting data and its implications for evaluating coating performance.

The Corrosion of Electrocoated Steel Studied by Accelerated Exposure and Electrochemical Methods

Pedro Atz Dick (PPG)

The assessment of corrosion performance in the automotive coatings industry most often relies on continuous salt spray exposure tests or cyclic tests, which typically consist of a combination of salt spray and cycles of humidity and temperature. Because the analysis of the results is usually limited to visual quantification of corrosion, these tests alone offer little information about the mechanisms of coating degradation and their rate of progression. On the other hand, electrochemical methods make use of electrical apparatus to detect, quantify, and accelerate or decelerate corrosion mechanisms.

In this work, electrochemical tests were employed in tandem with accelerated exposure tests to better understand the degradation mechanisms of electrocoated steel in corrosive environments. After receiving different electrocoats and undergoing different curing protocols, panels were ranked based on their performance in cyclic cabinet tests, full immersion in NaCl, or by accelerated electrochemical methods. Finally, the trends observed in corrosion behavior were compared, and conclusions were drawn based on the mechanisms captured by electrochemical techniques and their relevance in each testing protocol.

Corrosion Behaviour of an Iron Thermal Spray Coating for an Internal Combustion Engine

Jeffrey D. Henderson, Vahid Dehnavi, and Sridhar Ramamurthy (University of Western Ontario)
James Dante (Southwest Research Institute)

Over recent decades, the automotive industry has worked tirelessly to improve fuel efficiency in response to increasing environmental concerns and regulations. A significant portion of this effort has focused on substituting iron-based components with lightweight alloys. As a result, it has become the industry practice to fabricate large components, once made of iron-based materials, out of aluminum, magnesium, or other lightweight alternatives.

While aluminum offers attractive weight reduction, it may not meet the strength, wear, or hardness properties necessitated in applications where contact is made between moving components, e.g., between an engine bore and a piston ring. Here, a wear-resistant iron-based insert or coating is generally applied to achieve the necessary physical properties. However, corrosion within a combustion engine is a complex and dynamic system owing to the inherent variabilities of fuel composition and quality, operating temperatures, and general driving behaviour. After engine operation, during cool-down, the opportunity for water vapours to deliquesce onto internal surfaces becomes a concern in the corrosion process known as 'cold corrosion'.

During cold corrosion, several solution variables have the potential to accelerate the corrosion of iron-based coatings. To better understand the corrosion behaviour, a combination of electrochemical corrosion tests and surface analytical techniques were combined to study the corrosion behaviour of thermal spray coatings with solution parameters such as pH, F^-, and Cl^- (etc.). The role of coating microstructure was also studied in the context of thermal spray coatings. Data will be presented from a combination of results from field service parts and laboratory-based testing.

Advanced Characterization and In-situ Investigation of Zirconium-Based Pretreatment Coatings by Synchroton X-ray Spectroscopy Techniques

Kate Foster, Donald Vonk, Stanislas Petrash (Henkel)
Yu-chen Karen Chen-Wiegert and Xiaoyang Liu (Stony Brook University)
Kim Kisslinger, Mingyuan Ge and Evgeny Nazaretski (Brookhaven National Laboratory)

Metal pretreatments are used to impart corrosion protection, as part of the paint system, to protect vehicles from environmental factors. Recent developments toward more sustainable metal pretreatments have led to the industry adopting zirconium-based conversion coatings in place of traditional tri-cationic zinc phosphate. Metal pretreatment improves corrosion protection of the metal substrate and adhesion to the subsequent paint layers and the substrate. As the morphology and mechanisms of this type of coating are understood in greater detail, pretreatment coating formulations can be improved, leading to increased corrosion protection. The work presented will demonstrate studies on advanced characterization of such coatings, investigating in-situ growth of these coatings, and in-situ corrosion studies of zirconium-based metal pretreatment. Synchrotron X-ray techniques enable an in-depth analysis of the coatings, and an opportunity to study the coating in-situ, in real time, as the coating forms on the metal substrate, as substrates oxidize in a corrosive environment or to demonstrate how effective conversion coatings are at protecting the metal substrate in the corrosive environment.

New Corrosion Prevention Technologies

Exploring the Possibility of Adding Fire Preventative Capabilities to our Automotive Corrosion Preventative Coatings

Joe Desando (SWT Group)

Fire prevention is widely considered in the design and formulation of automotive coatings, especially in the development of Battery Electric Vehicles (BEVs), to help mitigate thermal runaway. In response to the current demand, SWT Group has developed a coating with potential to assist in mitigating thermal runaway in these vehicles. Our standard coating is a thin film, dry-to-touch coating designed for excellent chip resistance, and not necessarily for corrosion prevention. In addition, SWT Group formulates and manufactures many asphaltic- and wax-based corrosion preventative coatings supplied to automotive OEM and aftermarket industry. Therefore, we investigate the possibility of adding the benefit of thermal runaway mitigation to our traditional corrosion preventative products with the goal to emphasize both qualities within the product.

A developed fire preventative formulation is incorporated into our current asphalt-based and wax-based corrosion preventative coatings. Burn tests were performed using a propane torch (~1200°C) on our standard TRS coating, using aluminum panels since they burn through the fastest. Salt spray testing on the standard for each coating was conducted as a base line. Film thicknesses were determined using typical targets for performance requirements.

In this presentation, we discuss our current findings indicating varying levels of corrosion prevention depending on dry film thickness levels, additive levels and additive packages. Burn-through testing showed varying performances against the standard, and corrosion was rated through scribe on a panel and as percentage of red rust on the surface.

Plasma Electrolytic Oxidation Coatings on Light Alloys for Automotive Applications: Properties, Performance, and Prospects

Vahid Dehnavi, Sridhar Ramamurthy, Jeffrey D. Henderson, Mohammad Norouzi Banis, David W. Shoesmith, and Jamie Noel (The University of Western Ontario)

Plasma electrolytic oxidation (PEO) stands out as a promising surface engineering technology for light alloys, including aluminum, magnesium, and titanium. Its growing significance in diverse industries, such as automotive, aerospace, and biomedical, underscores its versatility and potential. This electrochemistry-based surface treatment process utilizes electric discharges to create multi-component oxide coatings that exhibit exceptional physical, mechanical, and chemical properties. These include improved wear and corrosion resistance, thermal stability, and dielectric properties. The automotive industry's transition towards electric mobility amplifies the significance of corrosion resistance, making PEO coatings increasingly relevant. Beyond conventional benefits like wear resistance, these coatings also play a crucial role in enhancing the longevity, performance, and safety of components in EVs. PEO coatings provide flexibility in formulating surfaces with specific properties, such as creating layers with specific insulating properties. These surfaces are essential for improving the safety of batteries and EVs for short-circuit prevention and thermal management. Furthermore, PEO coatings contribute to the sustainability aspect of electric vehicles, aligning with the industry's pursuit of environmentally friendly solutions.
This presentation investigates the properties of PEO coatings and summarizes our findings in designing the PEO process to achieve the desired coating properties required for different applications, mainly for corrosion and wear resistance.