User-Friendly Electrode Design for Real-Time Coating Condition Monitoring

Corrosion: How an Inevitable Process becomes a Technological Driver

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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General Research Problem

How does corrosion affect everyday life and why should people care about it?

Our world is a combination of multiple chemical reactions simultaneously occurring. We are surrounded by photosynthesis in plants, combustion in our gasoline engines, and even digestion and other processes happening in our bodies. One common chemical reaction that many people forget about, but has important side effects, is known as corrosion. A definition of corrosion is “the deterioration of materials as a result of reaction with their environment” (Ahmad, 2006, p. 2). Whenever a metal is exposed to a harsh environment, commonly an environment full of oxygen, hydrogen, or affected by an electric current, the metal will react and degrade, causing it to lose volume and lose its structural integrity. The reaction is due to the material wanting to go back to its lower energy “pure” state, which in metals is usually an oxide. Since all things in the universe wish to lower their free energy, there is a strong driving force for corrosion in metals that is always present (Shaw, 2006).

Someone unfamiliar with corrosion’s impact might wonder why we should care about this process. An example of corrosion would be an old bicycle, with its metal frame turning a red-orange color because of corrosion caused by the environment, i.e. the oxygen in the air (LaPlante, 2006). While an old bicycle doesn’t have major implications, other objects that corrode pose problems in cost, durability, aesthetics, and safety. Furthermore, a metal part in a bridge or plane must be in optimal condition during its entire lifespan, and if it corrodes and loses its integrity, will fail and cause the entire system to fail, endangering lives and costing tremendous amounts of money (Hansson, 2011). Anything made of metal has to deal with the fact that it will one day corrode, and thus it is paramount that manufacturers take into account corrosion for all applications. Research into this topic has increased steadily, and my technical project will attempt to aid in the identification and quantification of current corrosion damage in aircraft. In addition, my STS topic will look into the historic methods of defining, identifying, and preventing corrosion damage, and how they have allowed engineering to move forward, especially with regards to steel applications.

User-Friendly Electrode Design for Real-Time Coating Condition Monitoring

Can we create a "peel and stick" type electrode for real-time reliable and repeatable monitoring of corrosion-resistant coatings?

As previously stated, corrosion is a material concern for applications in harsh environments, such as salt water or environments with strong acids/bases. This project is interested in studying corrosion's effect on aircraft coatings, which is important for the public, private, and governmental sectors. If parts corrode on an aircraft, the parts can become compromised or cause a whole system to fail, which in turn, depending on the specific aircraft, will create a danger to human life. Alongside the safety issue it creates, replacing a corroded part puts a substantial cost on the operating entity, especially if the aircraft is old and parts are no longer created in large quantities. It is estimated that 60-80% of the total life cycle cost of a plane is spent in the operation and support phase, which means that the plane's major expenses are in keeping it operational (Clark, 2022). Of this maintenance period, almost a quarter of the maintenance costs are attributed to corrosion-related issues and repairs. This reveals an ambition of the aircraft industry in relation to corrosion, which is to create materials, coatings, and testing measures that will ultimately lower the cost that corrosion takes up in their budgets. LunaLabs is the sponsor of this Capstone project, and currently has research and prototyping underway in this field that hopes to improve on the current state of corrosion coating testing.

Currently, aircraft coatings are evaluated on a purely elapsed-time basis. Regardless of current damage or effectiveness, the coatings are inspected in specific intervals to make sure they are still operational. The time intervals are determined per aircraft and per the environment that the plane normally operates in. LunaLabs is currently making headway using electrochemical impedance spectroscopy (EIS), which uses an alternating potential across a region of interest to measure the current through the area. This in turn leads to the calculation of the signal impedance, which is the measure of the ability of a circuit to resist the flow of electrical current. Lower impedance values present during an EIS measurement mean that there is more corrosion and/or coating damage on the measured area. The drawback to this method is that it is very sensitive to electrode contamination, meaning it can only be used on samples either in a lab setting or where the contaminants are rigorously accounted for.

My project group will attempt to improve this current situation by developing a “peel and stick” electrode that will be used for in-situ testing for corrosion damage. The project will undergo three phases: planning, prototyping, and testing. The bulk of the time will be spent in the planning phase, where we will focus primarily on the material selection for the electrode and the specific geometry that we will use for optimal sample contact and measurement. Once we have a list of potential materials, prototypes can be manufactured for initial mechanical and electrochemical testing. If results are favorable and there is enough time, the prototypes will be tested in a real world application, made available by one of the sites owned by LunaLabs.

By the conclusion of this project, we will have a reliably functional electrode that was designed with many constraints in mind. The user experience is very important to our sponsor, and thus the prototype must be usable by a new or experienced user. Ideally, the electrode will be made of the best material for the application, in regards to the material's corrosion resistance, strength, and durability, with an initial goal of surviving 6 months outdoors in a harsh coastal environment. The prototype will also be easy and cost-effective to manufacture on a large scale. Another important aspect of this electrode prototype is its wettability in comparison to the coating and/or substrate material, which will ensure that the electrode will not slip off the base material, especially if the electrode is left attached for an extended period of time. Optimal wettability for the application is also useful as it ensures that the measurement is accurate since the full electrode surface will be in contact with the coating and/or base.

Corrosion: How an Inevitable Process becomes a Technological Driver

How has the evolution of corrosion knowledge and prevention allowed certain technologies to improve and thrive?

Through conversation with Professor Floro of the Materials Science and Engineering department at the University of Virginia, it was discussed that if there was an award for "most revolutionary material" in human history, in his opinion many academics would agree that there are two top contenders: silicon, because of its use in computer chips and electronic applications, and steel, because of its impact on the worlds infrastructure and its many uses across almost every imaginable industry. Steel is used in a huge variety of applications, from simple hand and kitchen tools to its use in larger applications like bridges, railroads, and buildings of all types (Spoerl, 2004). Because of the mentioned impact on many different areas, with many of these uses being in place long before computer chips were ever manufactured, the impact and importance of steel cannot be argued. Referencing the previous sections of this paper, a crucial property of steel that cannot be ignored is that it is made of iron, which means it will corrode eventually. We can look to examples of corrosion causing expensive preventive measures and safety concerns, from water boiler drums (Chattoraj, 1997) to aircraft bolts (Lee, 2007).

Steel is an interesting material because of its importance to worldwide modernization as well as its well documented history of innovation. Today we are fortunate enough to have many different types of steel at our disposal for any need, which all stemmed from early work starting with pure iron and early versions of rudimentary carbon steels (Spoerl, 2004). As steel was upgraded over the years however, it can be asserted that these innovations also progressed modern society, by giving people better quality materials to work with. As with many other materials, the constant push from industry and military research for more advanced materials were instrumental to the improvements in steel (Van Creveld, 2010). Because of these innovations in steel and their increased applications, the understanding of corrosion and application of this knowledge needed to increase at a similar rate, to the point where one could argue that steel has only come as far as it has because of our research into preventing steel corrosion from happening. It is fact to say that steel would be useless without understanding its corrosion properties and preventing corrosion from rendering the material useless or sub-optimal. To this extent, the purpose of this research will be to examine how corrosion became a “black box” for steel manufacturers, a routine property that is dealt with daily during production and assumed to be completely understood with current techniques (Latour, 1987).

In order to understand the events leading up to this black box forming, the history of steel itself must be researched and analyzed. It is necessary to look into what drove people to use steel in the first place and why research was constantly done on improving its properties. This will be done with special emphasis on exploring what role corrosion played in pushing innovation forward, and if there were any specific applications or industries that took the forefront on this issue. The data gathered will be chronological historical accounts of what was the forefront of steel research at that time, as well as reading into other important aspects like economics, environmental factors, and warfare. It will be interesting to look into any case studies or examples of failure caused by corrosion as well, since this would create a direct need for improvement that would drive the application forward, so that the failure would not happen again. The end goal would be to show a cyclic example of how science and technology interact with one another; as technology becomes more complex and ambitious, the science behind it must also evolve so that there is a great understanding of what is happening in technological applications and why.

Conclusion

The two projects described in this paper have goals based around the similar topic of corrosion science and understanding with respect to corrosion's impact on everyday life. The technical project has a tangible conclusion, which is to create an electrode prototype using the optimal material and geometry in order for it to survive at least 6 months of reliable use. The STS paper will hope to gain insight on the role of corrosion in the innovation of steel, with emphasis on any specific people, industries, or socio-technical systems that drove this forward.

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