How Machine Learning Can Accelerate Product Qualification Testing (PQT) and Avoid Costly Epoxy Coating Failures in LNG and Oil & Gas

By PCN Editor

Machine learning in combination with Electrochemical Impedance Spectroscopy (EIS) is a powerful means for the rapid screening of high-performance epoxy coatings for corrosion protection.

EIS is a potent technique for evaluating the corrosion protection performance of epoxy coatings. When combined with machine learning approaches, EIS testing can be used to efficiently screen and optimize epoxy coating formulations for enhanced corrosion resistance. This article explores how machine learning is being applied to EIS data analysis to accelerate the development and/or selection of high-performance epoxy coatings.

As an indication of the protective ability of epoxy coatings, the low-frequency impedance value of electrochemical impedance spectroscopy (EIS) data measured at 0.01 Hz (|Z|0.01Hz), can be used to estimate the overall corrosion resistance of the coating. A higher |Z|0.01Hz value represents a higher barrier ability of the coating. Based on the previous studies, the design of an ideal epoxy corrosion protective coating should have the following EIS index: The |Z|0.01Hz value of the aged epoxy coating being close to that of the intact initial coating; excellent barrier ability, |Z|0.01Hz value more than 10^{10} $\Omega \cdot cm^2$ and long-term EIS result stability in corrosive environments both before and after repair.

Often, the achievement of the target performance of self-healing implies synergy between multiple components of the epoxy coating formulation, including different resins, curing agents, liquid/solid additives, etc. The conventional trial-and-error design strategy for coating formulation is time-consuming and labour-intensive. Recently, machine learning methods have shown to represent a promising option for materials design and optimization, especially for systems with complex properties or compositions.

For example, Haik et al. developed a machine learning model to predict the stress relaxation properties of epoxy coatings, based on a three-layer neural network model using initial stress, test temperature and operating time as input variables and stress relaxation behaviour as output. The final model was obtained by training 9000 experimental data samples. This model can predict efficiently the time-dependent mechanical behaviour of epoxy coatings.

Advantages of Machine Learning for EIS Data Analysis

Machine learning offers several key benefits when applied to EIS testing of epoxy coatings:

• Rapid screening of multiple epoxy coating formulations

• Identification of complex relationships between epoxy coating composition and performance

• Prediction of long-term corrosion protection based on short-term EIS data

• Optimization of epoxy coating formulations to maximize corrosion resistance

Machine learning significantly improves the efficiency of epoxy coatings in several ways:

1. Predictive modelling: A machine learning workflow can predict the corrosion resistance of self-healing epoxy coatings containing specific components like barrier pigments and microfillers. This allows researchers to optimize epoxy coating formulations without extensive trial-and-error experimentation.

2. Rapid optimization: By using techniques like active learning and Bayesian optimization, researchers can quickly identify the best coating formulations. In one study, after just 5 cycles of active learning, a random forest model achieved good prediction accuracy for coating performance.

3. Improved performance: Machine learning-assisted design led to the development of a highly effective self-healing epoxy coating. The repaired coating showed impedance values nearly identical to the intact coating, indicating excellent healing properties.

4. Efficient parameter tuning: Machine learning helps optimize multiple parameters simultaneously, such as the molecular weight of curing agents, molar ratios of components, and filler content. This multi-dimensional optimization is challenging to achieve through traditional methods.

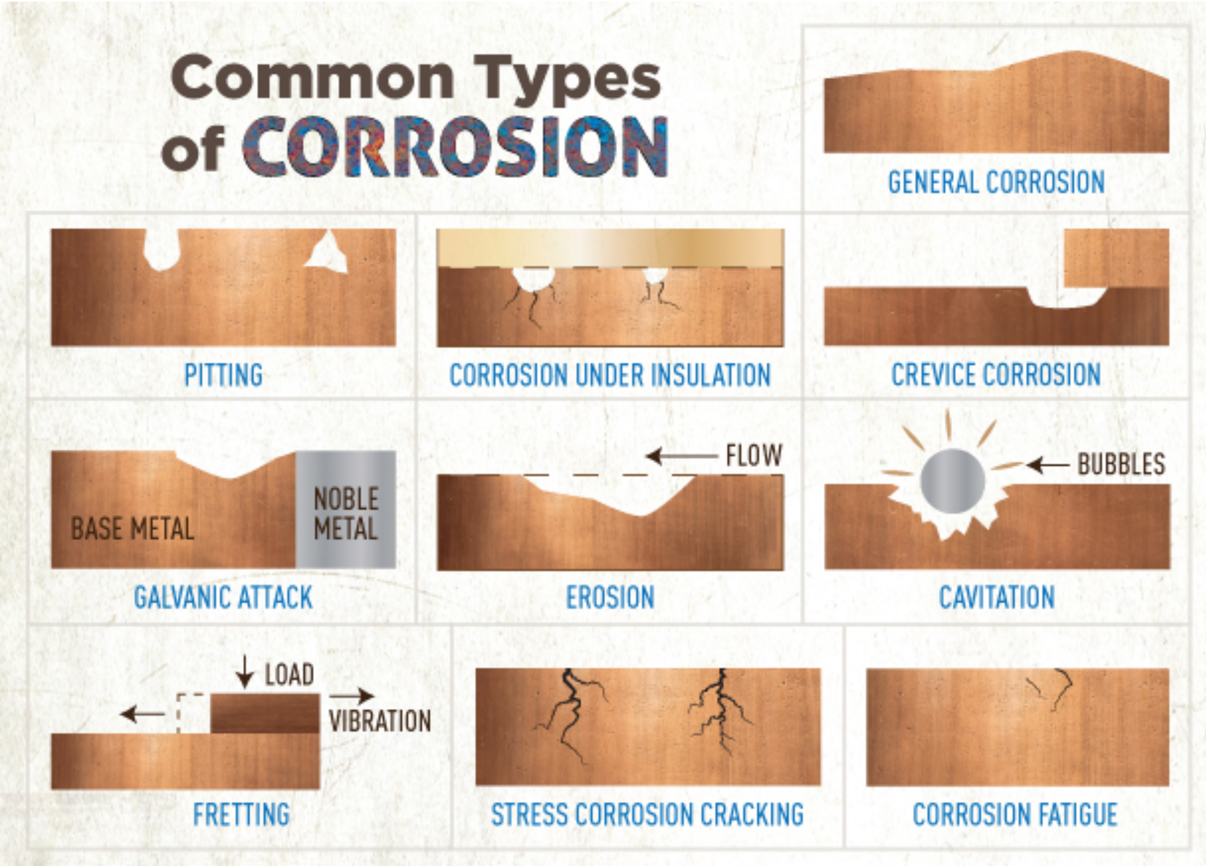
5. Time and cost savings: By predicting material properties and performance, machine learning reduces the need for extensive laboratory experiments, which can be time-consuming and expensive.

6. Exploration of complex relationships: Machine learning models can uncover non-obvious relationships between coating composition, structure, and performance that might be missed by conventional analysis.

7. Scalability: Once developed, machine learning models can be applied to design and optimize a wide range of epoxy coating formulations, accelerating the development of new materials.

By leveraging machine learning, researchers can more efficiently develop high-performance epoxy coatings with optimized corrosion resistance, barrier properties and self-healing efficiency, leading to faster innovation in this field.

ExcelPlas Coatings Labs https://www.excelplas.com/
provide a crucial role in this process, offering a holistic approach from coating preparation and application to rigorous testing and predictive analytics. Investing in thorough coating evaluation upfront is not just prudent but essential for safeguarding against costly failures in critical infrastructure. ExcelPlas Coatings Labs can determine the mechanism of coating breakdown and the mode of corrosion such as those depicted in the schematic below.



By adopting these practices, stakeholders can ensure that protective coatings not only meet but exceed performance expectations, thereby safeguarding investments and enhancing operational reliability in demanding industrial environments.