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Potentiostat-Independent Tools for Electrochemical Assessment of Performance of Coatings, Admixtures, and Corrosion Inhibitors

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ABSTRACT

Electrochemical assessment of coatings, admixtures, and corrosion inhibitors typically relies on potentiostats, which are cost-prohibitive and require expert handling. This limitation restricts their use in field testing, where validation of product specifications is often absent. To address this gap, we developed and tested potentiostat-independent tools for cost-effective, accessible, and reliable performance evaluation. Proprietary products, including corrosion inhibitors, concrete admixtures, and coatings, were assessed using three modalities: corrosion inhibitor performance meter, an accelerated corrosion testing device for coatings and admixtures, and dielectric testing of free films. Each test was benchmarked against a control specimen. These tools provided an effective alternative for evaluating anti-corrosion products and enabled cost-efficient, field-level testing. The study highlights the potential of such tools to transform performance validation practices across industries reliant on coatings, admixtures, and corrosion inhibitors

Keywords: *Corrosion inhibitors, coatings and admixtures, electrochemical assessment, dielectric testing*

1 INTRODUCTION

Corrosion of metals and deterioration of concrete structures present significant challenges in infrastructure maintenance, especially in environments exposed to moisture, salts, or industrial pollutants. To combat these challenges, the use of coatings, corrosion inhibitors, and admixtures has become standard practice. However, ensuring the efficacy of such protective systems demands reliable performance testing. Conventionally, this has relied on electrochemical methods [1] using potentiostats—highly sensitive instruments that require controlled environments and expert operation. While effective in laboratory settings, potentiostats are expensive, complex, and unsuitable for routine field assessments, leaving a critical gap in practical, on-site validation.

In many real-world scenarios—construction sites, maintenance checks, or product verification—such instruments are unavailable or impractical. Consequently, many products are applied without sufficient performance verification, increasing the risk of premature failure, material wastage, and safety hazards. The absence of accessible testing also hampers quality assurance, especially in regions or sectors with limited laboratory infrastructure.

To address these constraints, we have developed a suite of low-cost, portable, and user-friendly prototype tools as part of a unified field-testing approach capable of evaluating the corrosion resistance and dielectric behavior of coatings, admixtures, and corrosion inhibitors. The focus is on the methodology, which can be applied with different tool designs. By eliminating the dependence on potentiostats, these tools open the door to practical, repeatable field testing that aligns with industrial demands.

2 RESEARCH SIGNIFICANCE

This work addresses the critical gap between lab-based electrochemical assessment and field-level product validation in corrosion technology. The novelty lies in the transferable testing methodology that prioritizes the approach over the specific instruments, enabling adaptation to a varied industrial context. By developing novel, potentiostat-independent tools tailored for coatings, admixtures, and corrosion inhibitors, we introduce a practical pathway for on-site, cost-effective testing. These tools bypass the need for expert operation, enabling broader accessibility and real-world performance evaluation. The methodology directly bridges the disconnect between specification and application, offering scalable solutions for infrastructure durability and industrial reliability.

3 MATERIALS AND METHODS

Three complimentary test modalities were developed and demonstrated through prototype tools to evaluate the performance of corrosion inhibitors, coatings, and concrete admixtures without the use of a potentiostat. These include: Inhibitor Performance Meter (IPM), Accelerated Corrosion Testing Device for Coatings and Admixtures, Dielectric Testing Setup for Free Films.

Figure 1 Accelerated Corrosion Testing of Coatings and Admixtures. a), b) Various coatings onto concrete lollipop samples immersed in 3.5% NaCl water, c) Accelerated Corrosion Testing Tool with the voltage output and current drawn displayed

Each tool was designed for cost-effectiveness, ease of use, and portability to suit both lab and field applications. Standard specimens, control samples, and proprietary products were used in all tests.

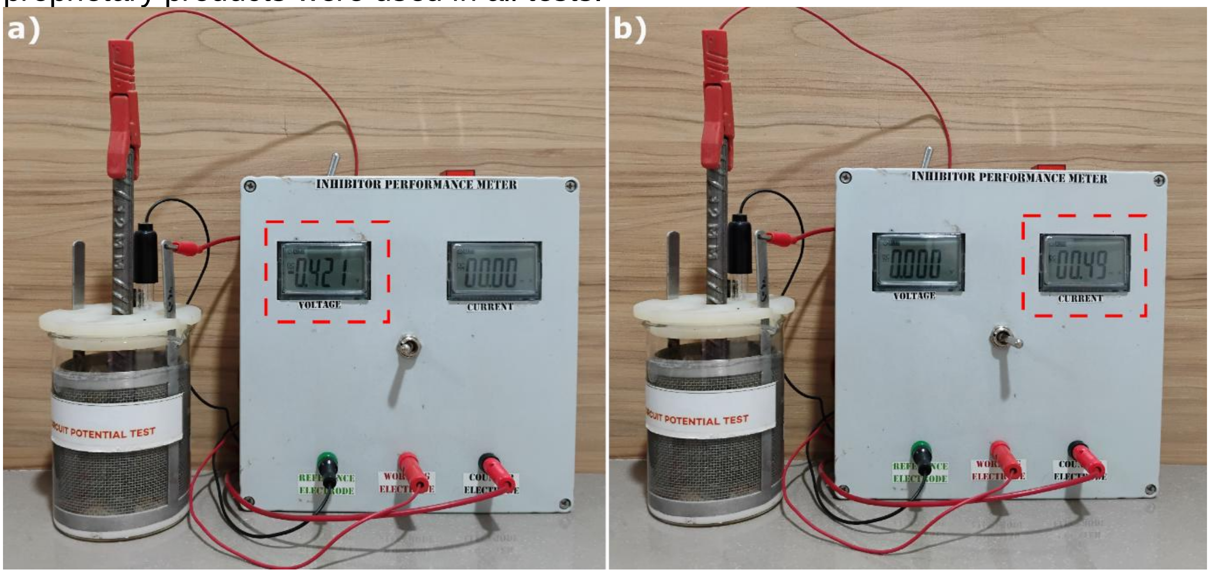

Figure 2 Inhibitor Performance Meter. a) OCP of rebar with respect to calomel electrode, b) Current between the counter electrode and the rebar

Inhibitor Performance Meter (IPM)

The IPM consists of a custom-fabricated set-up to measure voltage and current changes over time in a corrosion cell. Mild steel rebars were immersed in saline solution with and without corrosion inhibitors. After attaining equilibrium condition, the OCP and current measurements are made. On the addition of the corrosion inhibitor, the OCP and current are again measured and compared. Effect of varying concentration of the inhibitor is also studied using this tool.

Accelerated Corrosion Testing of Coatings and Admixtures

To compare the amount of current consumed by a test sample, a constant potential is imposed on it. Each test sample constitutes the concrete lollipop sample with and without various coatings, immersed in a salt solution. A steel mesh is used as a counter electrode. The imposed voltage accelerates the corrosion activity and enables us to simulate an aggressive corrosive environment [2]. The physical condition of the samples was periodically inspected and documented. The current drawn by these samples is measured. Further, coatings with different thicknesses are tested.

Dielectric Testing of Free Films

Dielectric properties of free film coatings were evaluated using a parallel plate electrode probe as per the ASTM D150 standard [3]. Free films were clamped between two conductive plates [4], and capacitance was measured at 1 kHz by an LCR meter. This setup was designed to provide insights into film integrity and dielectric performance without destructive testing. Both proprietary and control films were subjected to this method under identical conditions.

Each test was repeated multiple times on both control samples and proprietary coating systems to assess the repeatability and consistency of the measurements. All samples were prepared under consistent conditions to minimize variability. Curing, exposure time, and environmental conditions were consistent across all tests.

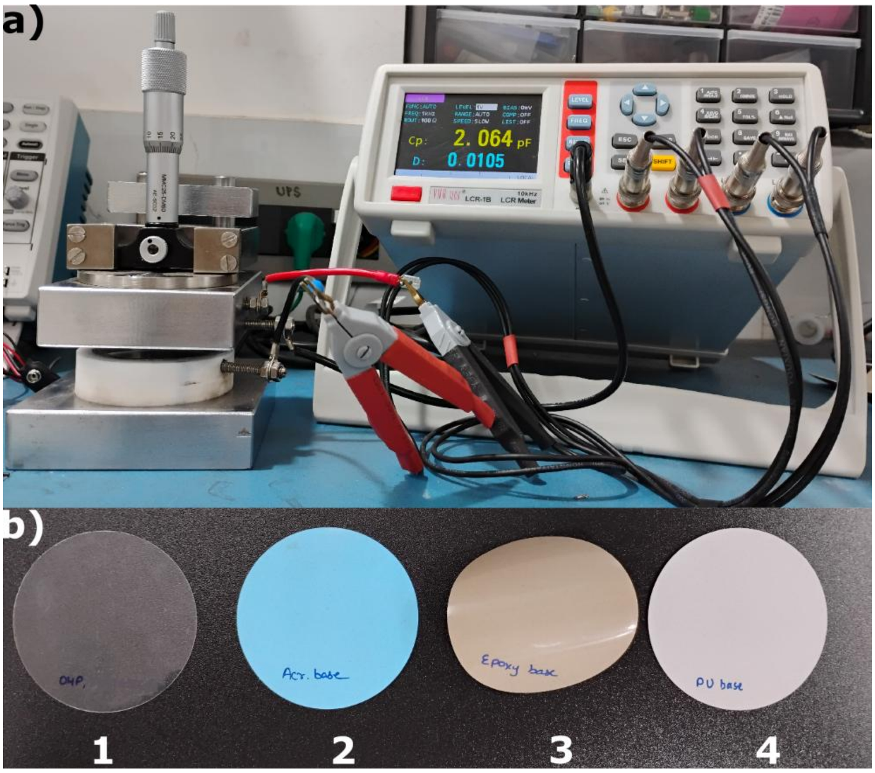

Figure 3 a) Dielectric constant test setup, with the capacitance probe on the left and the impedance analyzer on the right, b) Samples of free films used: 1. OHP, 2. Acrylic, 3. Epoxy, 4. Polyurethane

4 RESULTS AND DISCUSSION

The experimental results obtained from the three potentiostat-independent tools are presented and discussed in this section. While these results come from a specific prototype designs, they validate the broader potentiostat-independent approach, which can be implemented with alternative configurations. Each tool—Inhibitor Performance Meter (IPM), Accelerated Corrosion Testing Device, and

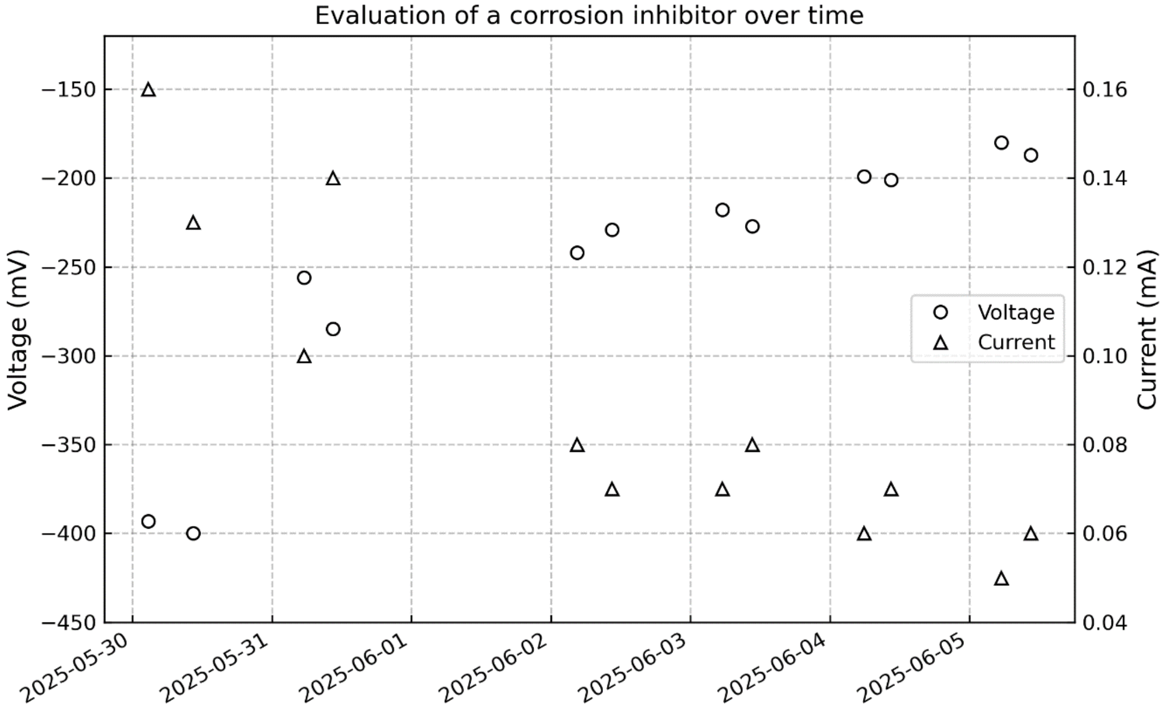

Figure 4 Variation of open circuit potential and corrosion current over 7 days, showing increased passivation and reduced corrosion rate with the inhibitor.

Dielectric Testing Setup—was applied to evaluate the performance of corrosion inhibitors, concrete admixtures, and protective coatings. The findings consistently showed clear differentiation between control and treated samples, validating the sensitivity and repeatability of the methods.

For the corrosion inhibitors, a progressive increase in open circuit potential and a decline in corrosion current were observed with higher dosages, indicating enhanced passivation and kinetic suppression. Similarly, coating assessments via accelerated corrosion testing demonstrated that epoxy-based coatings provided complete suppression of current under aggressive conditions, whereas other coatings offered varying degrees of protection. Dielectric testing of free-standing films assessed the use of dielectric constants of these films as a quality metric. Across all tests, control samples were included in each trial and repeated measurements confirmed the reliability of the tools. These results support the feasibility of low-cost, field-deployable electrochemical assessment and suggest a scalable pathway for validating performance claims of anti-corrosion products outside laboratory settings. The findings align with theoretical expectations and existing literature, while also introducing a novel testing framework with practical utility in construction, infrastructure, and materials research.

Inhibitor Performance Meter (IPM)

Figure 4 presents the electrochemical evolution of a corrosion inhibitor applied to steel surfaces, monitored over a period of 7 days. The open circuit potential (OCP) and corrosion current were tracked simultaneously to evaluate the degree of corrosion protection.The OCP (represented by circles) shows a significant improvement from approximately –400 mV indicates an increasing tendency toward passivation, suggesting the formation of a protective layer due to the inhibitor's action.

Conversely, the current (depicted as triangles, right y-axis) demonstrates a consistent decline from 0.16 mA initially to values below 0.06 mA by the end of the test period. This reduction signifies a decrease in corrosion rate, confirming the inhibitor's effectiveness in suppressing electrochemical activity at the metal surface. The dual-axis representation enables clear visualization of the inverse relationship between the corrosion potential and current. Together, the shift toward nobler potentials and reduced current density strongly support the effectiveness of the tested inhibitor in providing durable corrosion protection under the examined conditions.

Figure 5 illustrates the variation of open circuit potential difference (ΔOCP) and corrosion current ratio as a function of inhibitor concentration. A consistent increase in ΔOCP is observed with rising concentration up to 1.5%, indicating enhanced stability of the passive layer. Beyond this point, ΔOCP shows a marginal decline, suggesting possible saturation or redistribution effects at higher dosages.

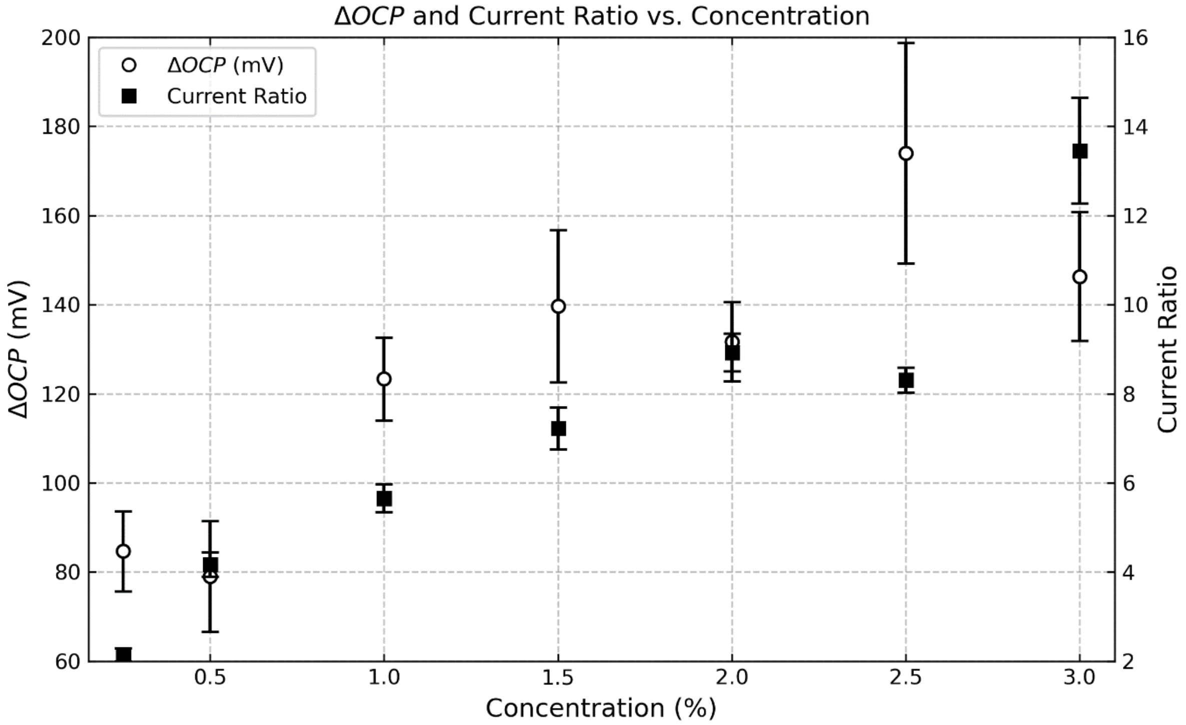

Figure 5 Effect of inhibitor concentration on ΔOCP and current ratio.

The corrosion current ratio, plotted on the secondary axis, exhibits a monotonic increase across the entire concentration range, with the highest ratio (~14) observed at 3.0%. This suggests significant kinetic suppression of corrosion, even when the potential gain plateaus. This dual improvement in both thermodynamic and kinetic parameters confirms the inhibitor's effectiveness and highlights its concentration-dependent performance.

Accelerated Corrosion Testing of Coatings and Admixtures

Accelerated corrosion testing is performed on coated concrete specimens immersed in 3.5% NaCl solution using a potentiostat-independent tool operating at 2 V DC (Figure 2c). The current drawn by each sample was recorded as an indicator of corrosion activity. As shown in Table 1, the uncoated control sample exhibited the highest corrosion current (7.3 mA), indicating severe corrosion. In contrast, the epoxy-coated sample showed complete suppression of corrosion with a current of 0 mA, while acrylic and coal tar coatings exhibited significantly lower corrosion currents of 0.6 mA and 0.4 mA, respectively. These results demonstrate the tool's capability to quantify the effectiveness of protective coatings through electrical current measurements.

Coat System	Control	Epoxy	Acrylic	Coal Tar
DFT (µm)	0	225	150	200
Current (mA)	7.3	0	0.6	0.4

Table 1 Accelerated corrosion current values for various coatings (Lower is better)

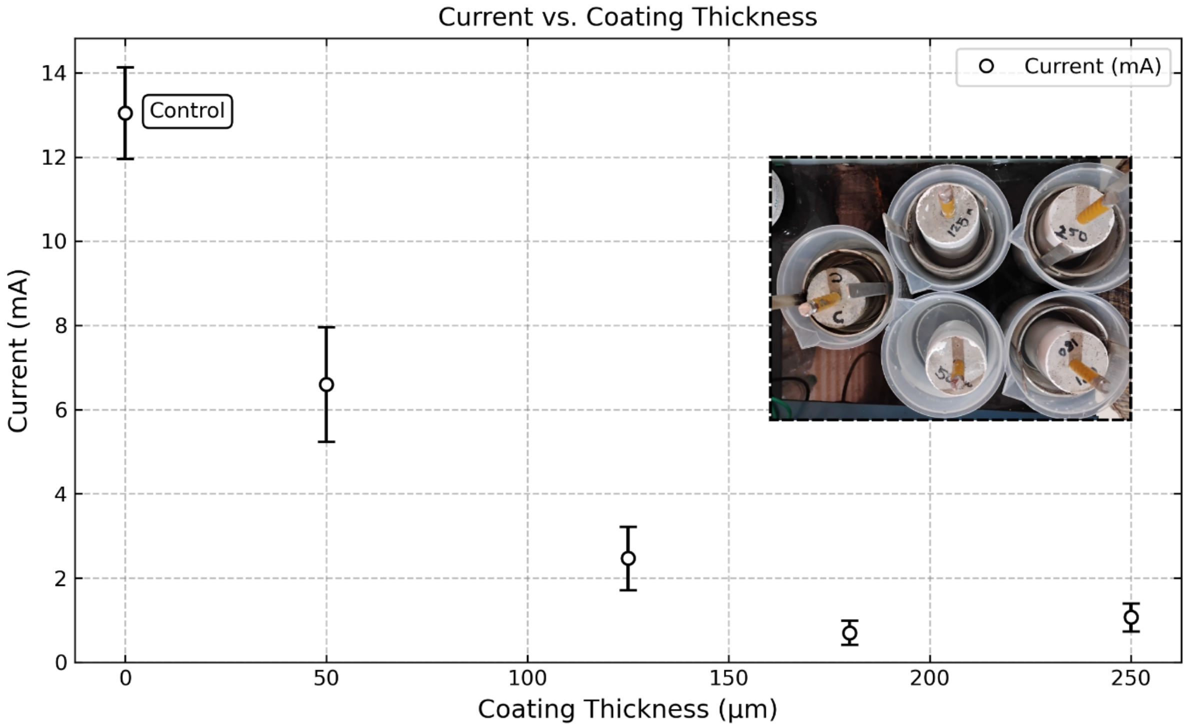

Figure 6 Effect of acrylic coating thickness on current response in 3.5% NaCl solution after 24 hours of immersion. The uncoated control shows the highest current, while increasing coating thickness results in a progressive reduction in current. Inset: Setup showing coated samples labeled with corresponding thickness values (0, 50, 125, 180, 250 micrometers respectively)

Figure 6 illustrates the influence of acrylic coating thickness on the current response of metallic samples immersed in a 3.5% NaCl solution. The uncoated control sample exhibited the highest current (~13 mA), indicating significant electrochemical activity. As the coating thickness increased, a substantial reduction in current was observed. At 50 µm, the current decreased to ~6.5 mA, further dropping to ~2.5 mA at 125 µm. For coatings of 175 µm and 250 µm, the current stabilized below 1 mA, indicating effective suppression of electrochemical processes beyond a certain thickness threshold.

All coatings were fully cured prior to immersion, and measurements were conducted after 24 hours of exposure to the saline environment. The inset image shows the prepared samples labeled by coating thickness, verifying consistency in the experimental setup. Error bars indicate standard deviations across repeated trials, demonstrating good reproducibility. These results confirm that acrylic coatings offer increasing electrochemical protection with thickness, although marginal gains diminish beyond 125 µm.

Dielectric Testing of Free Films

The dielectric properties of four free-standing coating films—OHP, acrylic, epoxy, and polyurethane—were evaluated using a parallel-plate capacitance probe connected to an impedance analyzer, as shown in Figure 3a. The films, prepared with distinct dry film thicknesses (DFT) ranging from 190 µm (OHP) to 540 µm (epoxy), were tested for their dielectric constant under ambient conditions. Representative samples of the films are shown in Figure 3b. As summarized in the accompanying table, the measured dielectric constants were lowest for OHP (2.0) and highest for acrylic (ranging from 4 to 8), with epoxy and polyurethane exhibiting intermediate values of 2.7 and 2.4, respectively. These values are consistent with the known polymer chemistry of the respective materials and serve as a baseline for interpreting changes in dielectric behavior upon exposure to aggressive environments or additives.

Free Film	OHP	Acrylic	Epoxy	Polyurethane
DFT (µm)	190	300	540	410
Dielectric constant	2	4 – 8	2.7	2.4

Table 2 Dry film thickness and dielectric constant values of the free-standing coating films used in this study. The OHP sheet was used as a control, while the other films represent common protective coating formulations.

5 CONCLUSIONS

This study successfully demonstrates that potentiostat-independent approach implemented through prototype tools can be used to evaluate the electrochemical performance of corrosion inhibitors, coatings, and admixtures in a cost-effective and field-deployable manner. Three distinct tools—Inhibitor Performance Meter (IPM), Accelerated Corrosion Testing Device, and Dielectric Testing Setup—were developed and validated against control and proprietary samples. The results indicate that these tools not only provide repeatable and reliable measurements, but also offer valuable insights into the thermodynamic and kinetic behavior of corrosion systems and the dielectric integrity of coating materials. By eliminating the reliance on expensive laboratory potentiostats, the proposed methods make electrochemical assessment accessible to industries and infrastructure stakeholders operating outside traditional lab environments.

6 ACKNOWLEDGMENTS

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