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Corrosion Behaviour of SS316 in 3.5% NaCl: A TiO_2 Thin-Film EIS Study

Raja Naveen Varma Kucharlapati, Susanta Sinha Roy

Rohrback Cosasco Systems Inc., 11841 Smith Avenue, Santa Fe Springs, CA 90670, USA

Department of Physics, School of Natural Science, Shiv Nadar University, India – 203207

INTRODUCTION & METHOD

Stainless steel SS316 is the workhorse alloy of marine, petrochemical, and biomedical industries, prized for its Cr-Ni-Mo passive oxide film. However, chloride ions aggressively penetrate and displace this passive film, triggering localized pitting and crevice corrosion that drastically reduce component service life.

Corrosion costs the global economy an estimated US$2.5 trillion annually (3.4% of global GDP), with available best practices able to save US$375–875 billion per year (NACE IMPACT, 2016).

Aim: To evaluate whether an RF-sputtered TiO_2 thin film can enhance the corrosion resistance of SS316 in 3.5 wt.% NaCl, using Electrochemical Impedance Spectroscopy (EIS) and linear polarization to quantify the protective effect.
Materials: SS316 (ASTM A276/A240; 17% Cr, 12% Ni, 2.5% Mo) abraded with SiC papers (120→1200 grit), cleaned, and immersed in freshly prepared 3.5 wt.% NaCl (AR grade, DI water >18 MΩ·cm).

TiO_2 Coating: Deposited by RF magnetron sputtering (~10^{-7} Torr base pressure, 20 mTorr working pressure, Ar/O_2 = 30/12 sccm, 12 rpm rotation) to a thickness of ~50 nm.

Electrochemistry: AUTOLAB PGSTAT302N, 3-electrode cell (SS316 WE ~1 cm², Pt mesh CE, Ag/AgCl RE, +0.197 V vs. SHE). EIS: 0.1 Hz–1 MHz, 10 mV AC. Linear polarization: ±0.1 V vs. OCP, 1 mV/s. All tests at 23±2°C, in triplicate.

TEST SETUP

Figure1: TiO_2-coated SS316 specimen

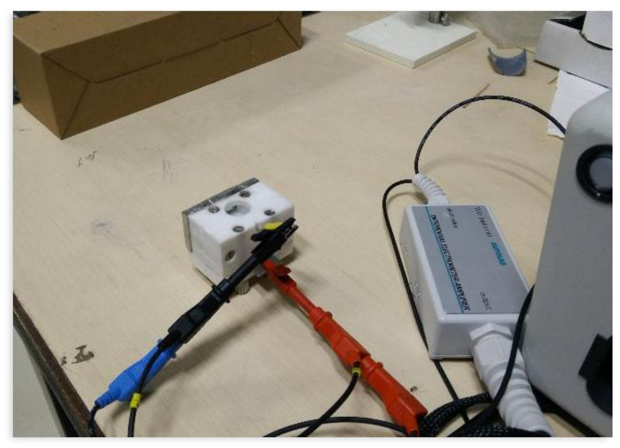

Figure 2: AUTOLAB PGSTAT302N electrochemical cell

RESULTS & DISCUSSION

EIS Nyquist plots (Figs. 1–2) show bare SS316 impedance contracting from ~60,000 Ω (Day 2) to ~28,000 Ω (Day 4), confirming passive film breakdown, with partial re-passivation by Day 8. In contrast, TiO_2-coated SS316 exhibits –Z″ > 130,000 Ω on Day 1 — a 77% increase over bare SS316 at the same time point — and remains protective through Day 3.

Linear polarization (Figs. 3–4) confirms this trend quantitatively: corrosion current (icorr) drops by 94.9% and corrosion rate falls by ~70% with the TiO_2 coating, while Ecorr shifts +4 mV toward more noble behaviour — both EIS and polarization data independently agree.

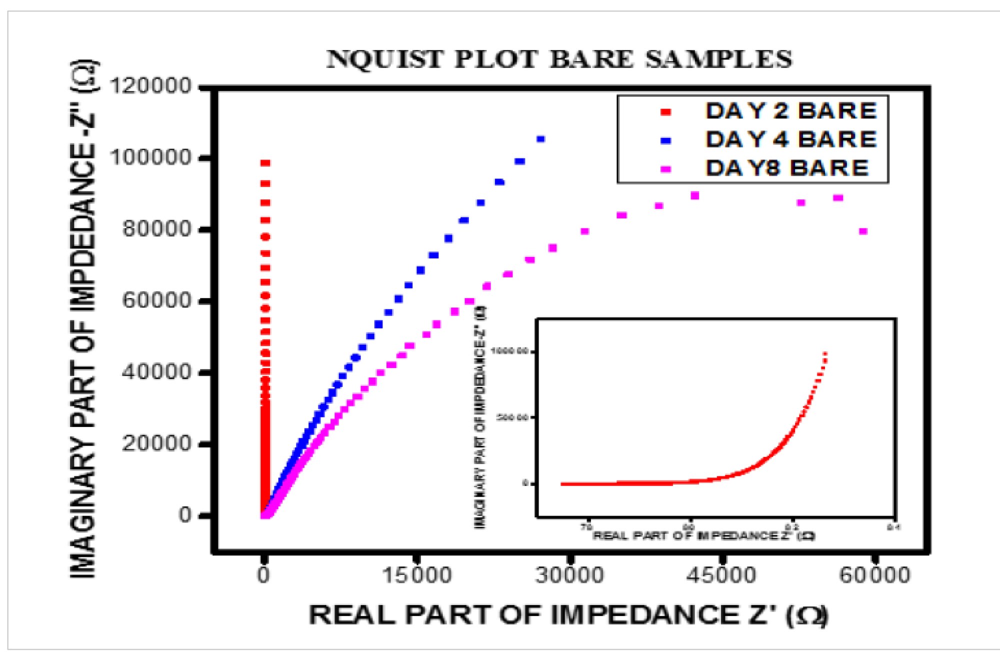

Figure 3. Nyquist plot — bare SS316 (Day 2, 4, 8). Z′ contracts from ~60,000 Ω (Day 2) to ~28,000 Ω (Day 4), confirming passive film breakdown.

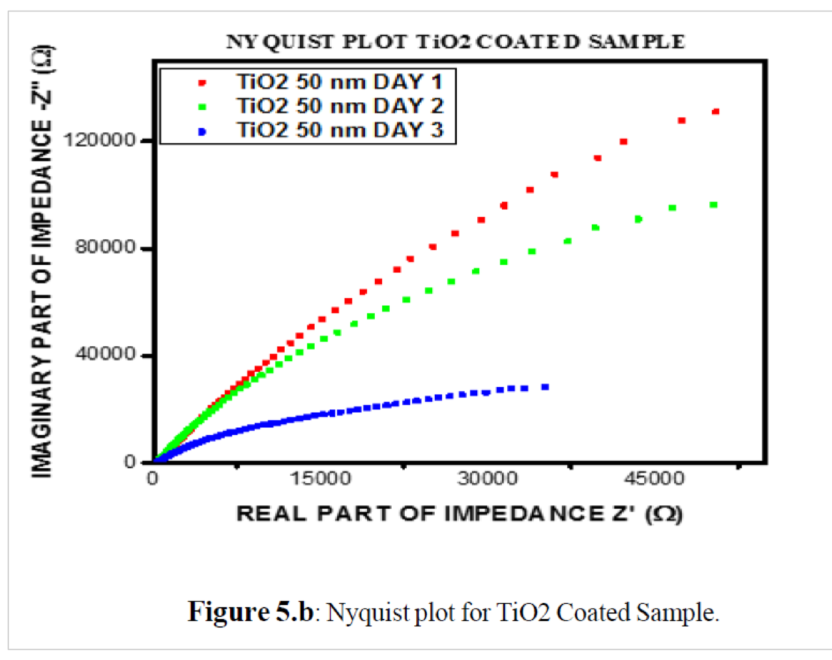

Figure 4. Nyquist plot — TiO_2-coated SS316, 50 nm (Day 1, 2, 3). –Z″ exceeds 130,000 Ω on Day 1 — the largest impedance recorded in this study.

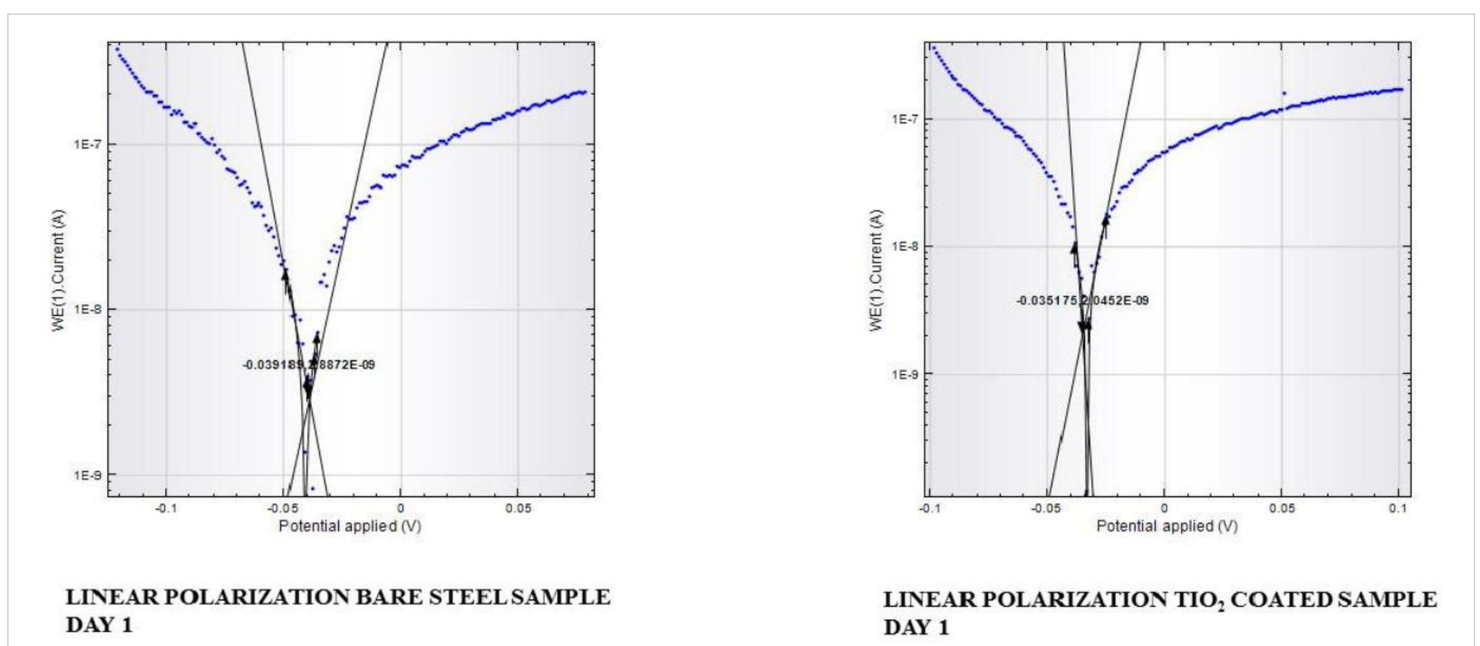

Figure 5. Linear polarization curves, Day 1. Bare: Ecorr = −0.039 V, icorr = 0.889 nA. TiO_2-coated: Ecorr = −0.035 V, icorr = 0.0452 nA (−94.9%).

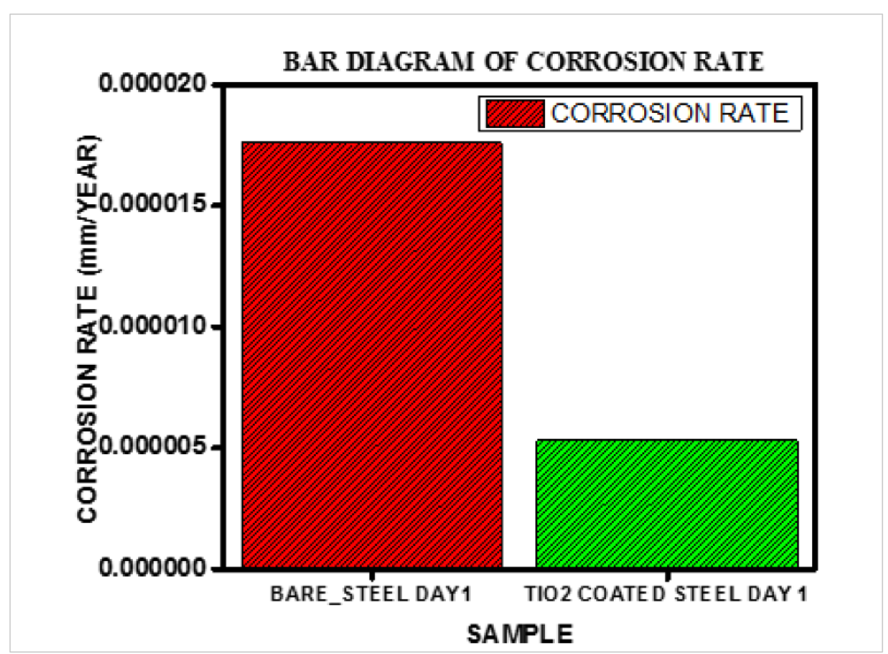

Figure 6. Corrosion rate comparison, Day 1. TiO_2 coating reduces corrosion rate by ~70% (1.77×10^{-5} → 5.3×10^{-6} mm/year).

Ecorr Shift	icorr Reduction	Corrosion Rate	EIS Impedance (Day 1)
+4 mV	−94.9%	−70.1%	+77%
−«0.039» V → −0.035 V	0.889 nA → 0.0452 nA	1.77×10^{-5} → 5.3×10^{-6} mm/yr	75,000 Ω → 133,000 Ω

CONCLUSIONS

- RF-sputtered TiO_2 thin films (~50 nm) significantly enhance the corrosion resistance of SS316 in 3.5 wt.% NaCl, confirmed independently by both EIS and linear polarization.
- Corrosion rate reduced by ~70% (1.77×10^{-5} → 5.3×10^{-6} mm/year); icorr reduced by 94.9%; EIS impedance increased by 77% at Day 1.
- The protective effect is attributed to a stable, compact TiO_2 barrier layer that limits electrolyte access and suppresses charge-transfer reactions — directly relevant to marine, petrochemical, biomedical, and desalination industries.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Future Work: XRD/SEM/XPS characterisation; 50 nm vs. 100 nm thickness comparison; CPE equivalent circuit modelling; extended immersion studies.

Selected References: 1. Koch et al., NACE IMPACT Study, 2016. 2. Pan, Thierry & Leygraf, J. Biomed. Mater. Res., 1997. 3. González-Torres et al., Surf. Coat. Technol., 2023. 4. Santos et al., Steel Res. Int., 2024. 5. Revilla et al., Electrochim. Acta, 2020.

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