

Evaluation of Coatings Suitability for Buried SS316L Pipelines

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ABSTRACT

Six polymeric coatings viz 3LPE, 3p/2p CAT, PU, VE, LE, and HSS have been selected, and each type of coating has been applied separately on SS316L pipe external surface. The test samples were subjected to Specific Electrical Insulation Resistance (SEIR) test in 0.1 mol/liter of NaCl solution and the Electrochemical Impedance Spectroscopy (EIS) test in 3.5 % NaCl solution. After completion of the tests, SEIR values of PU, 3LPE, and LE are found to be about 2.5×10^9 , 8.9×10^8 , and 3.9×10^8 ohm.m², respectively. In contrast, the electrochemical impedance values at low frequencies (100 mHz) of 3LPE, 3p/2p CAT, and HSS are found to be about 7.9×10^{11} , 5.4×10^{11} , and 4.5×10^{11} ohm.cm², respectively. The experimental results are analyzed, and the ranking of coatings has been made based on each test's performance. The overall ranking of coatings is evaluated for the determination of the suitability of the coating for buried SS316L pipelines in the petroleum, petrochemical, and natural gas industries. Prog. Color Colorants Coat. 16 (2023), 361-375 © Institute for Color Science and Technology.

1. Introduction

The petrochemical products are transported via buried SS316L pipelines. These pipelines are installed mostly buried and marginally overground. Overground SS316L pipelines do not need corrosion protection due to 1-3 nm (nanometre) thick chromium oxide (Cr₂O₃) passive layer [1, 2]. In buried condition, an uncoated SS316L pipeline is excellent in high-resistivity soil with a good drainage system [3]. Still, an uncoated SS316L pipeline is uncertain in low-resistivity soil with chloride ions (Cl⁻) and an oxygen deficiency [4]. Cl⁻ ions destroy the passive layer and lead to forming of corrosion pits on the SS316L surface [5]. The porous corrosion products cover pits and remain undetectable until they leak [6]. Localized pitting corrosion penetrates rapidly to the thickness of the SS316L pipeline and perforates the SS316L pipeline within a few days [7]. The mechanism of pitting corrosion and

the subsequent failure of buried SS316L pipeline are shown in Figures 1 a and b. It is, therefore, imperative to apply external polymeric (organic) protective coatings on buried SS316L pipelines for the safe transportation of petrochemical products.

A thorough literature survey, including analysis of research papers, reveals that so far, most of the studies on polymeric coatings focused primarily on the analysis of coatings performances and suitability for buried carbon steel pipelines. Many researchers have devoted research efforts to studying metallic and organic coatings on SS316L substrates for marine environments or to studying the pitting corrosion of SS316L under thermal insulation. But, to date, less attention has been paid to the research on coatings performances and suitability for buried SS316L pipelines, and there is a research gap that remains unanswered in this field. To address this outstanding

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gap, the present study has chosen six external polymeric coatings commonly used for buried carbon steel pipelines in the petroleum, petrochemical, and natural gas industries for buried SS316L pipelines. Each type of coating has been applied separately on each 4-inch SS316L pipe external surface after surface preparation. The test samples extracted from the coated SS316L pipes have been subjected to SEIR and EIS tests to investigate the coatings' electrical and electrochemical properties, barrier, or degradation properties. The experimental data are evaluated by comparing the coating's performances and determining the suitability of the coating for buried SS316L pipelines in the petroleum, petrochemical, and natural gas industries.

2. Experimental

2.1. Chemical composition analysis and corrosion tests of SS316L material

Test samples were drawn from 4-inch SS316L pipes for chemical composition analysis and corrosion tests. Cyclic potentiodynamic polarization test [8] was conducted at 25 °C using a three-electrode system within a glass cell filled up with 3.5 % sodium chloride (NaCl) solution according to ASTM Standard Test Method G61 [9]. After 1 hour of immersion, scanning was done at a rate of 10 mV/minute within a potential range from - 400 mV to + 600 mV with Gill AC Potentiostat with 5 channels, Make ACM Instruments [10]. Critical Pitting Potential (CPP, E_{PTT}) values were evaluated from the polarization plots. Significant pitting corrosion was observed under Scanning Electron Microscopy (SEM), Model No. EVO 40, Make: Carl Zeiss AG [11]. A critical Pitting Temperature (CPT) test was conducted at

22-24 °C in reagent grade 6 % ferric chloride (FeCl_3) solution as per ASTM Standard Test Method G48 [12] in determining the minimum temperature to produce a pitting attack on the SS316L surface.

2.2. Surface preparation of SS316L pipes

The external surfaces of 4-inch SS 316L pipes were prepared by fused alumina fine particles for a high level of adhesion [13]. Surfaces were made dry and free from contamination prior to coating. Fused alumina particles, original pipe surface, and pipe surface after blasting are shown in Figure 2 a, b, and c, respectively.

2.3. Types of polymeric coatings

Six generic types of polymeric coatings have been selected, and each type of coating has been applied separately on each 4-inch SS316L pipe external surface after surface preparation. The generic types of coatings are as follows:

1) 3Layer Polyethylene (**3LPE**), 2) 3ply/2ply Cold Applied Tape (**3p/2p CAT**), 3) Solvent-free Liquid-applied Polyurethane (**PU**), 4) Non-crystalline Visco-Elastic polyolefin with polymeric tape outer wrap (**VE**), 5) Solvent-free Liquid-applied Epoxy (**LE**) and 6) Polyethylene-based Heat-Shrinkable Sleeve (**HSS**).

The specifications that address requirements for qualification, application and testing of external coatings for buried or submerged carbon steel pipelines in the petroleum, petrochemical and natural gas industries are considered applicable to external coatings for buried SS316L pipelines. Brief descriptions of coatings, including application method and drying time, are given below:

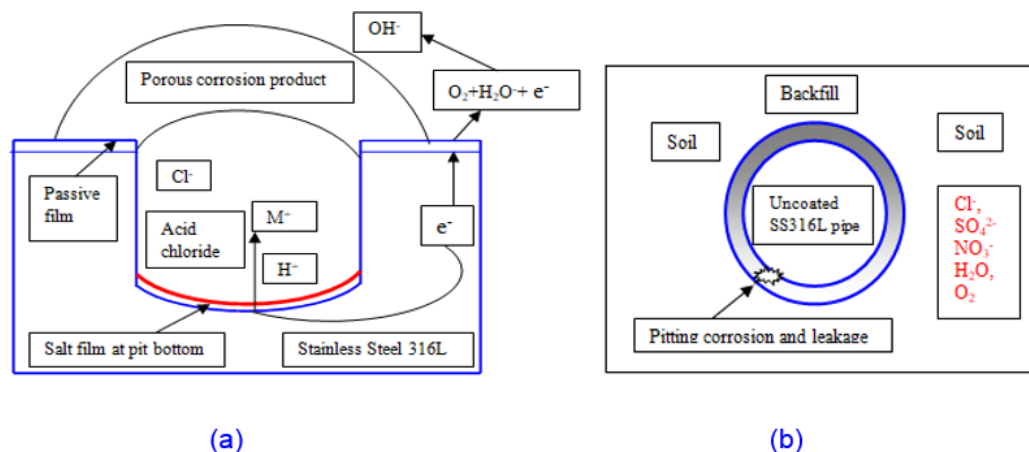


Figure 1: (a) Schematic diagram on mechanism of pitting corrosion, (b) Failure of buried SS316L pipeline.

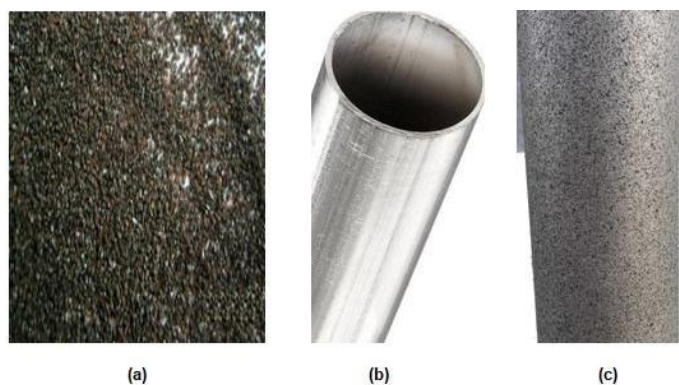


Figure 2: Surface preparation of SS316L pipe - (a) fused alumina fine particles, (b) original pipe surface and (c) pipe surface after blasting.

1) 3Layer polyethylene (3LPE)

This coating system is plant-applied three-layer side extruded polyethylene and conforms to the requirements as per ISO 21809-1 [14]. This anti-corrosion system consists of a high-performance fusion bonded epoxy primer (FBE, minimum 200 microns) first layer followed by a copolymer adhesive second layer (a maleic anhydride grafted polyethylene compound, about 200-250 microns) and the third layer is an outer layer of high-density polyethylene, HDPE (about 2400-2600 microns) with UV stabilizers, which provides tough, durable protection. After blasting and cleaning the pipe from contamination, the pipe is heated by induction heating at about 200 °C. FBE powder is sprayed on this heated pipe surface. FBE easily melts and provides excellent adhesion to steel. The adhesive layer is applied by extrusion before the gel time of FBE coating. Extruded polyethylene layer is applied over the adhesive layer immediately. 3LPE coated pipe is then sent for water quenching and holiday detection test. This coating system is applied in the plant only. This coating system provides corrosion protection of buried pipelines at operating temperatures from - 40 to 80 °C.

2) 3ply/2ply Cold applied tape (3p/2p CAT)

The cold-applied multilayer coating system conforms to the requirements as per ISO 21809-3 [15] and consists of a liquid adhesive primer (butyl rubber), a 3ply anti-corrosion inner layer (HDPE and butyl rubber co-extruded coating), and a mechanical outer layer (MDPE with UV stabilizers). After blasting, the pipe surface is made clean & dry and free from contamination. A liquid adhesive primer (about 80-100

microns) is applied uniformly on the pipe surface. 3ply anti-corrosion inner layer (tape thickness about 800 microns) is applied spirally (with no less than a 50 % overlap) over the primer when it is dry to touch. The outer layer (tape thickness of about 500 microns) is also applied spirally (with no less than a 50 % overlap) over the inner layer. The applied thickness of 3p/2p CAT is about 2500 microns or more. This coating system is applied in the plant and the field. This coating system provides corrosion protection of buried pipelines at the maximum operating temperature of 55 ± 5 °C.

3) Liquid-applied polyurethane (PU)

An aromatic thermoset polyurethane is a reaction product of a polyol (resin) and diphenylmethane diisocyanate (MDI, activator). Liquid-applied PU coating is solvent free (100 % volume solid) and conforms to the requirements as per ISO 21809-3. After thoroughly mixing the resin and activator (typically 3:1 ratio in volume), the coating is applied by using heated plural component airless equipment to the blast-cleaned pipe surface to achieve a thickness of about 1000-1500 microns in a single coat. This coating system is applied in the plant and the field. This coating system provides corrosion protection of buried pipelines at operating temperatures from - 20 to 80 °C.

4) Non-crystalline visco-elastic polyolefin with polymeric tape outer wrap (VE)

This cold-applied non-crystalline, non-cross-linked, non-reactive poly-isobutene wrap (about 2000-2500 microns thick) has a direct bond to the substrate. and

conforms to the requirements as per ISO 21809-3. Over poly-isobutene wrap, an ultraviolet-resistant flexible polyvinyl chloride (PVC, about 500 microns thick) tape coated with a rubber resin adhesive is applied. This coating system is applied in the plant and in the field. This system provides corrosion protection for buried pipelines at the maximum operating temperature of 60 °C.

5) Liquid-applied epoxy (LE)

A high-build solvent-free (100 % volume solid) consists of two-component (part-A and part-B) novolac based epoxy and conforms to the requirements as per ISO 21809-3. After thoroughly mixing part A and part B (usually 3.5:1 ratio in volume), the coating is applied by using heated plural component airless equipment to the blast-cleaned pipe surface to achieve a thickness of about 800-1500 microns in a single coat. This coating system is usually applied in the field. This coating system provides corrosion protection of buried pipelines at the maximum operating temperature from - 20 to 80 °C.

6) Heat-Shrinkable Sleeve (HSS)

A wrap-around heat-shrinkable sleeve replicates the plant-applied 3LPE coating and conforms to ISO 21809-3. The first layer is solvent free two component liquid epoxy primer (about 200 microns), the second layer is copolymer hot melt adhesive (about 200 microns), and the third layer is radiation cross-linked HDPE with UV stabilizers (about 2000-2500 microns thick). The blast-cleaned pipe surface is heated at about 80 °C, and solvent-free two-component liquid epoxy primer is applied to the pipe surface. Heat-Shrinkable Sleeve is wrapped around immediately over the wet epoxy. The sleeve is then heated with a propane torch until it shrinks and fits tightly around the joint. This coating system is mostly applied in the field for field joints and is sometimes applied in the plant for pipe bend joints. This coating system provides corrosion protection of buried pipelines at the maximum operating temperature of 80 °C.

2.4. Preparation of test samples - thickness measurements and holiday tests

The test samples of the coating materials were prepared after cold cutting pipe segments from main 4-inch coated pipes to conduct SEIR and EIS tests. The SEIR and EIS tests were carried out for each coating of the three samples. DeFelsko digital thickness gauge, Model No. PosiTector 6000, Make DeFelsko Inspection Instruments [16] performed the thickness measurement of the coating. The entire surface of each coating was subjected to a holiday test by the holiday detectors, Model Nos. DC-05 (up to 5 kV) and SD-120 (from 8kV to 30 kV), Make Associate Electronics [17] applying voltage based on the type of coating and thickness as per NACE Standard SP0274 [18] to ensure each coating surface was free from holidays (pinholes or defects).

2.5. SEIR tests of coatings

SEIR test is a very simple and convenient experimental method that covers a procedure for quantitatively measuring the specific electrical insulation resistance of a coating by applying a Direct Current (DC). Three test samples of each coating were immersed vertically in 0.1 mol/liter of NaCl solution (0.58 % NaCl solution) in the plastic container according to International Standard ISO 21809-3. Caltech Specific Electrical Insulation Resistance Tester, Model No, performed SEIR test. SISR-05, Make: Caltech Engineering Services [19] at 23-25 °C for 100 days of immersion. The submerged pipe end of the coated sample was sealed with a non-conductive sealant so that there was no contact with the NaCl solution. During each measurement, the pipe end of the coated sample in the open air and not immersed was connected to the positive pole of the DC power supply. The negative pole of the DC power supply was connected to the counter electrode, a copper rod of 10 cm². The measurements were taken at intervals with an applied voltage of 100V. A schematic diagram of the SEIR test and a coated sample under SEIR testing are shown in Figure 3a and b, respectively. Six types of coated test samples immersed in NaCl solutions in plastic containers are shown in Figure 4.

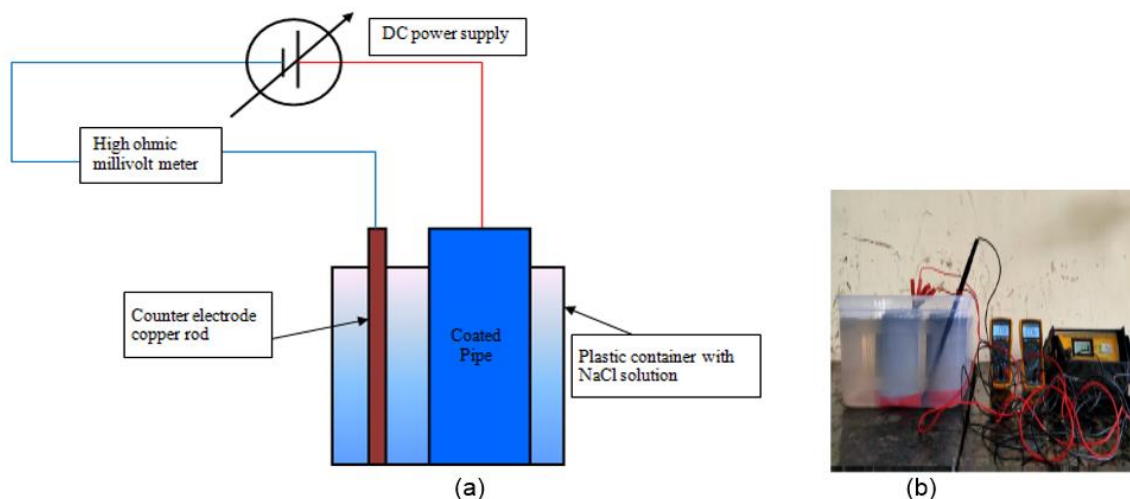


Figure 3: (a) Schematic diagram of SEIR test and (b) A coated sample under SEIR testing.

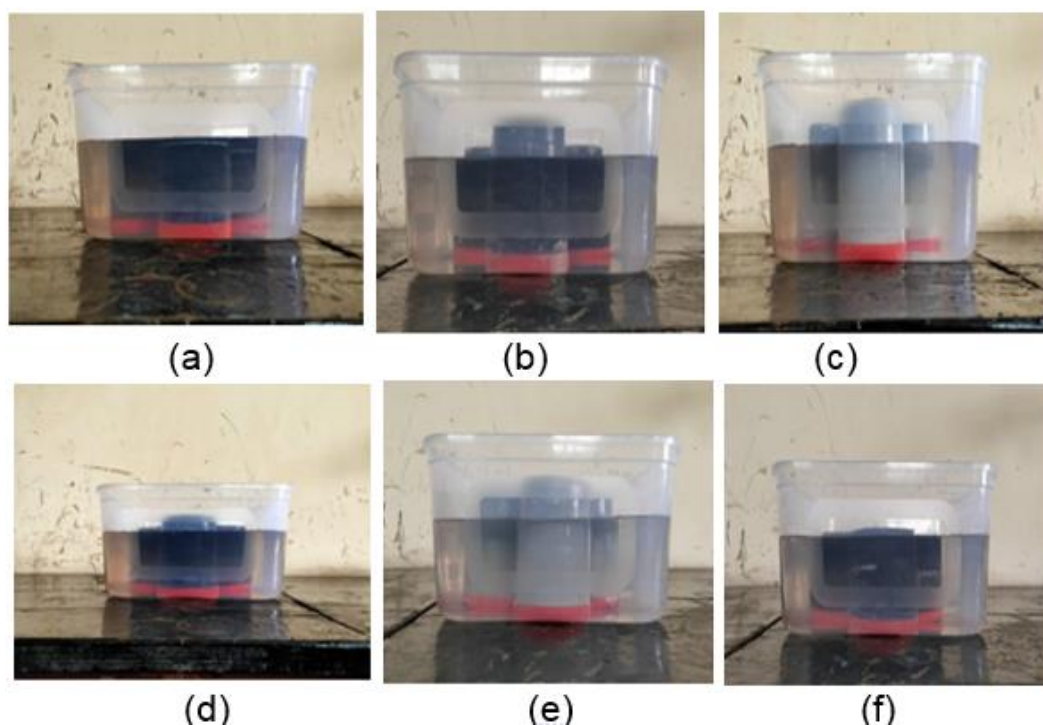


Figure 4: Coated test samples –(a) 3LPE, (b) 3p/2p CAT, (c) PU, (d) VE and (e) LE, (f) HSS.

2.6. EIS tests of coatings

EIS test method is an Alternating Current (AC) impedance method for measuring the impedance and capacitance of a coating quantitatively, for investigating the electrical and electrochemical properties, barrier, or degradation properties of a coating [20-22]. EIS measurements, and data generated within short testing times are more reliable to predict the long-term performance of coatings. Therefore, EIS is a well-established method to investigate the corrosion

resistance and anti-corrosion performance of protective coatings [23]. The experimental procedure for collecting electrochemical impedance data was performed according to ASTM Standard Practice G106 [24] with the attached cells consisting of glass tubes cemented to coated SS316L pipes. The attached cell contained a coated pipe surface as Working Electrode (WE), a graphite rod as Counter Electrode (CE), and a Saturated Calomel Electrode (SCE) as Reference Electrode (RE). The attached cell was filled with 3.5 % NaCl solution.

CE and RE were inserted into the solution. EIS tests were done on three-layer samples by GAMRY Instruments, Model No. Reference 600+, Make GAMRY Instruments [25] at 23-25 °C for 14 days. The measurements were carried out on the 1st day, 7th day, and 14th day at open circuit potential with an applied AC voltage of 100 mV_{rms} in amplitude in the frequency range of 100 kHz - 10 mHz. During data collection of

electrochemical impedances and capacitances, the samples were placed inside the Faraday cage to minimize electromagnetic interference and noise. A Schematic circuit diagram of the EIS test and a coated sample inside the Faraday cage under testing are shown in Figures 5a and b, respectively. Six types of coated test samples with attached cells are shown in Figure 6.

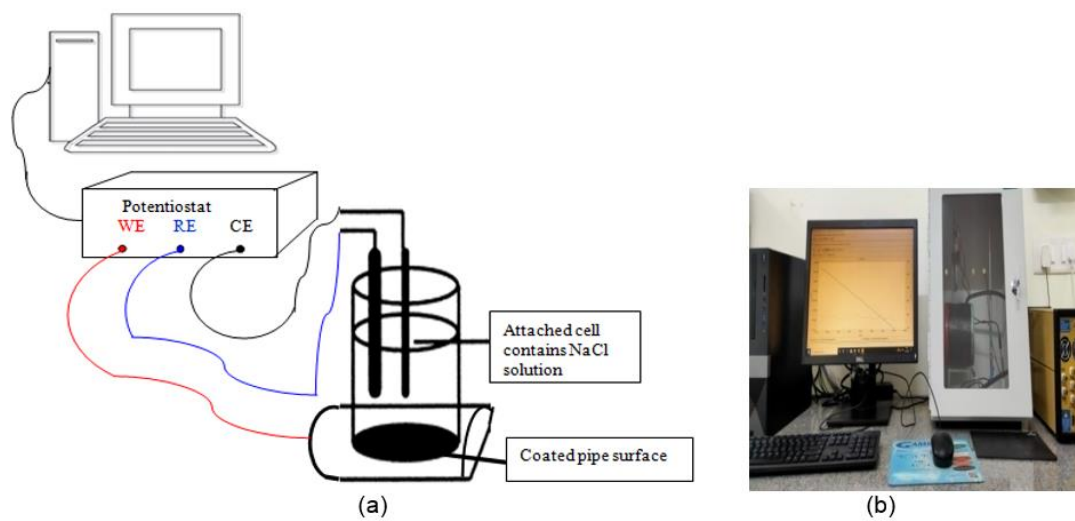


Figure 5: (a) Schematic diagram of EIS test and (b) A coated sample under EIS testing.

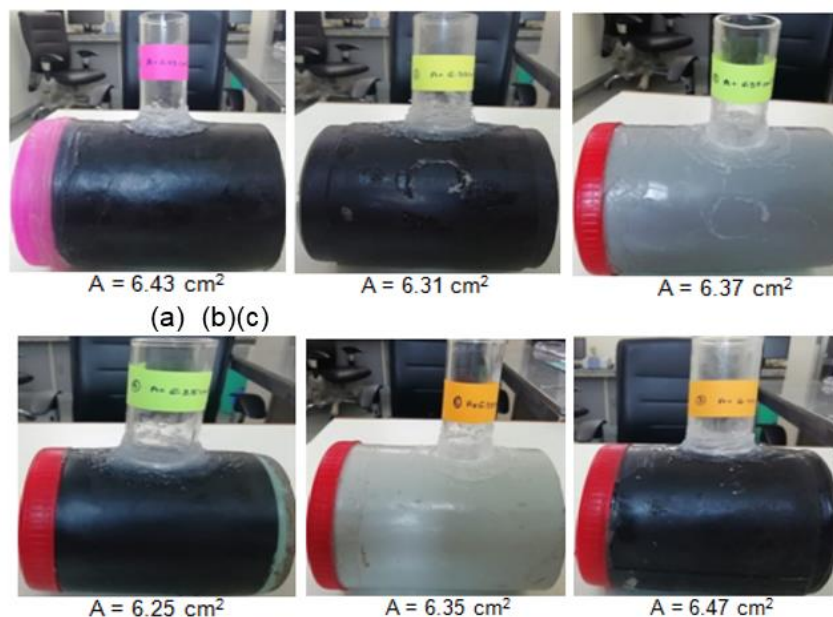


Figure 6: Coated test samples—(a) 3LPE, (b) 3p/2p CAT, (c) PU, (d) VE and (e) LE, (f) HSS (A=attached cell area in cm²).

3. Results and Discussion

3.1 Chemical composition analysis and corrosion tests results of SS316L material

The results of the chemical composition analysis and corrosion tests of SS316L are reported in Table 1 and Table 2, respectively. The cyclic potentiodynamic polarization plots of test samples are shown in Figure 7.

The chemical composition analysis of SS316L conforms to ASTM Standard Specification A312 [26]. It is observed from the cyclic potentiodynamic polarization plots that the current increases steeply to E_{PIT} , which indicates the onset of stable pits formation

from the transient metastable pitting. From E_{PIT} , the current increases sharply, indicating the transition to transpassive corrosion, a state of rapid dissolution of metal resulting in significant pitting corrosion, and the destruction of protective Cr_2O_3 passive film on the SS316L surface in the presence of Cl^- ions. Significant pitting corrosion has been observed under Scanning Electron Microscopy (SEM) examination after the cyclic potentiodynamic polarization test, as shown in Figure 8. CPTs have been found to be 15-16 °C, which indicates that SS316L is susceptible to localized pitting corrosion in chloride-bearing environments much below room temperature.

Table 1: Chemical composition analysis of SS316L.

Test Sample	C %	Mn%	S %	P %	Si %	Cr %	Ni %	Mo%	N (ppm)*	Fe %
Sample 1	0.021	1.24	0.005	0.042	0.26	16.32	10.05	2.03	380	Bal.
Sample 2	0.022	1.25	0.004	0.043	0.27	16.08	10.06	2.03	395	Bal.
Sample 3	0.018	1.27	0.004	0.043	0.20	16.29	10.05	2.04	440	Bal.

(ppm)* - parts per million Bal. - balance amount

Table 2: Corrosion test results of SS316L.

Test Sample	E_{PIT} (mV) vs. SCE *	CPT (°C)	Mass loss corrosion rate (g/cm ²)
Sample 1	361	16	0.02071
Sample 2	363	15	0.02598
Sample 3	380	16	0.01519

SCE * - saturated calomel electrode as the reference electrode

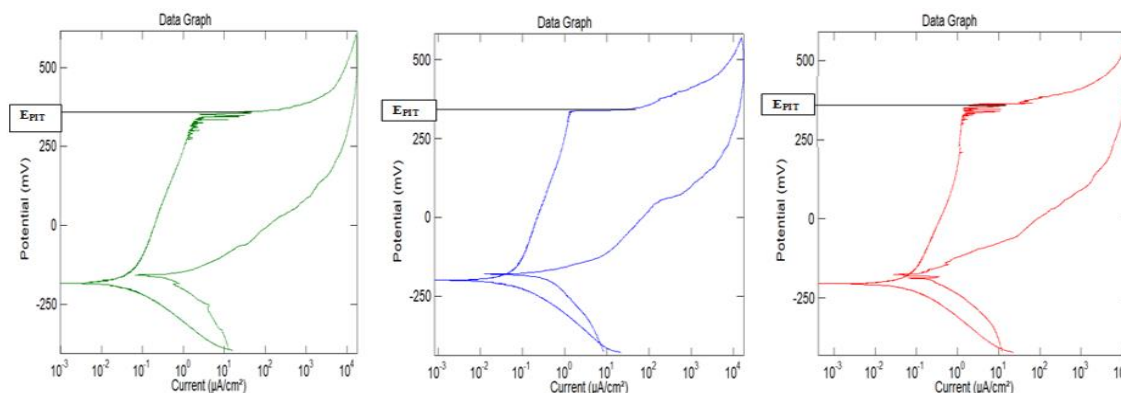


Figure 7: Cyclic potentiodynamic polarization plots of SS316L test samples.

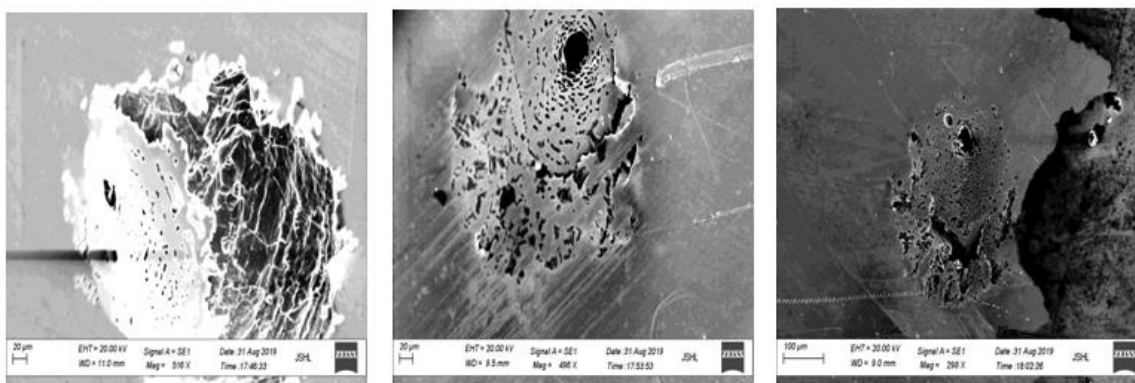


Figure 8: SEM photographs on pitting corrosion of SS316L samples after polarization test.

3.2. Thickness measurements and holiday tests results of coatings

The thickness measurement report and the applied voltages for holiday tests are shown in Table 3.

3.3. SEIR test results

SEIR values of the coatings are shown in Figure 9. From these graphs, the initial SEIR values of 3LPE, PU, and LE coatings are found to be greater than 10^9 ohm.m², whereas SEIR values of 3p/2p CAT, VE, and HSS are found to be greater than 10^8 ohm.m². Six coatings with such high initial specific electrical resistances reveal perfect insulators that yield higher corrosion protection. After 100 days of immersion, SEIR values of coatings are found to be reduced. This phenomenon is likely to happen due to exposure of a coating to a corrosive environment over some time and

due to water absorption by the polymeric coating on metal substrate resulting in loss of insulating properties and corrosion protection efficiency.

To differentiate the performances of six types of coatings, a comparison has been drawn based on the SEIR values versus 100 days of immersion in 0.1mol/liter of NaCl solution (0.58 % NaCl solution) at 23-25 °C and is shown in Figure 10. It appears from Figure 10 that PU has the highest SEIR value. In comparison with other coatings, PU has better-insulating resistance than 3LPE, and 3LPE has better resistance than LE. VE has shown better resistance than 3p/2p CAT and HSS. Therefore, the ranking of six types of coatings concerning their performance in SEIR testing is found to be PU-1, 3LPE-2, LE-3, VE-4, 3p/2p CAT-5, and HSS-6, where '1' represents the highest performance.

Table 3: Thickness Measurement (in mm) and Holiday Test (in KV) of coatings.

Type of coating	1	2	3	4	5	6	7	8	Av.*	Vol.**	Holidays
3LPE	2.96	2.93	2.89	2.93	2.98	2.86	2.85	2.80	2.9	20	Nil
3p/2p CAT	2.48	2.52	2.55	2.49	2.51	2.52	2.45	2.48	2.5	19	Nil
PU	1.7	1.65	1.49	1.5	1.48	1.57	1.58	1.43	1.55	8	Nil
VE	3.03	3.09	3.07	2.95	2.91	3.03	2.89	3.1	3.0	22	Nil
LE	0.96	1.06	0.92	0.97	0.92	0.9	0.92	0.95	0.95	5	Nil
HSS	2.31	2.22	2.45	2.3	2.46	2.24	2.2	2.22	2.3	18	Nil

Av.* - arithmetic mean of thickness

Vol.** - minimum applied voltage

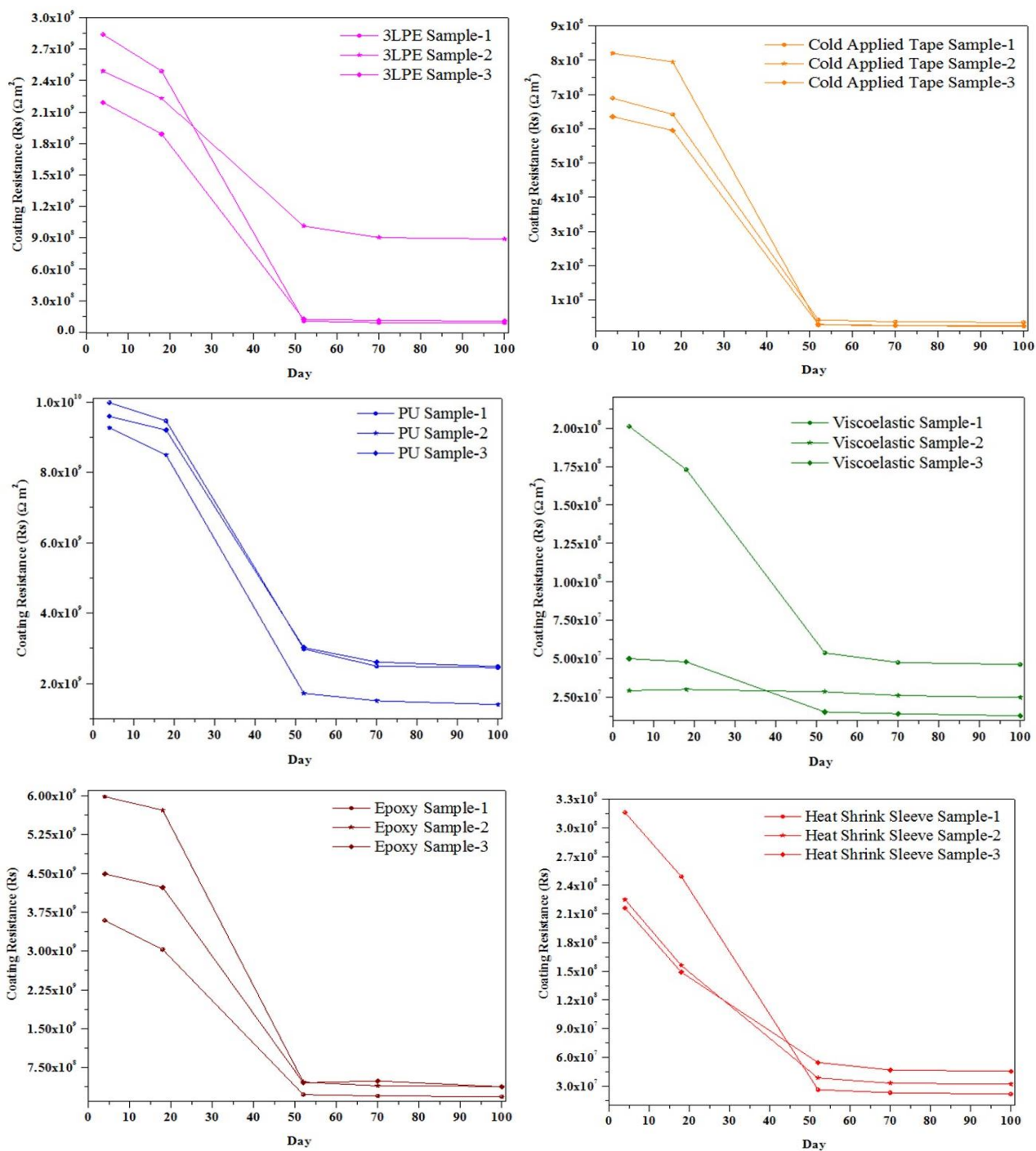


Figure 9: SEIR values of six coatings.

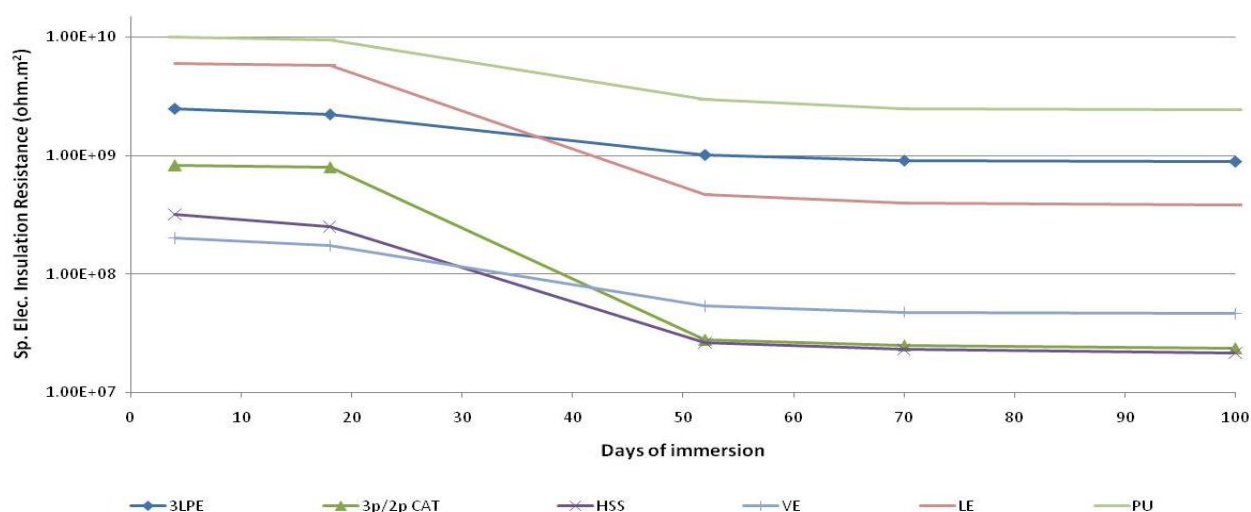


Figure 10: A comparison of SEIR values of six coatings for 100 days of immersion in 0.1 mol/liter of NaCl solution at 23–25 °C.

3.4. EIS tests results

The Bode plots represent the data and spectra generated during EIS tests. These plots are interpreted as impedance magnitudes, $|Z|$ in ohm.cm^2 (left side Y1 vertical axis in log scale) and phase angles, Φ in degree (right side Y2 vertical axis) versus the measured frequencies in Hertz (Hz) (horizontal X axis in log scale). A common legend has been used for the Bode plots of six types of coatings and is shown in Figure 11. The Bode plots of six types of coatings are shown in Figure 12 and Figure 13.

It is observed from the Bode plots of six types of coatings that the impedance values versus frequencies are diagonal, and their slopes are -1 [27]. Six types of coatings have shown high impedance values at the lowest frequencies, which are greater than 10^{11} ohm.cm^2 , although little variations in impedance values have been observed for HSS, VE, and LE. The impedance values of six coatings types are also greater than 10^5 ohm.cm^2 at higher frequencies. Overall, six types of coatings are found to be good insulators.

Phase angles of 3LPE and 3p/2p CAT versus frequencies are found to be almost -90° and a little less

than -90° , respectively. It has been revealed that 3LPE and 3p/2p CAT behave as better capacitors. The variations of phase angles at lower frequencies have been observed on PU, VE, LE, and HSS coatings, and the phenomena indicate that there is a likelihood of permeating water, oxygen, ions, and corrosive species through the coatings into the metal substrates beneath due to exposure to the corrosive environments over some time and the coatings may lose insulating properties. Water causes swelling by transporting ions into the coating. When water uptake is low, the coating resistance is high because of low permeation of oxygen, ions, and corrosive species. It has been reported that diffusion is a prime mechanism of water absorption in polymeric coating and plays a significant role on water uptake. One of the studies conducted by EIS on polymeric coating has reported that there are four different stages for water uptake by the coating and they are (1) water absorption rapidly in the initial days, (2) increased water uptake with a slower rate, (3) saturation of water, and (4) lastly, a further increase in water absorption [28].

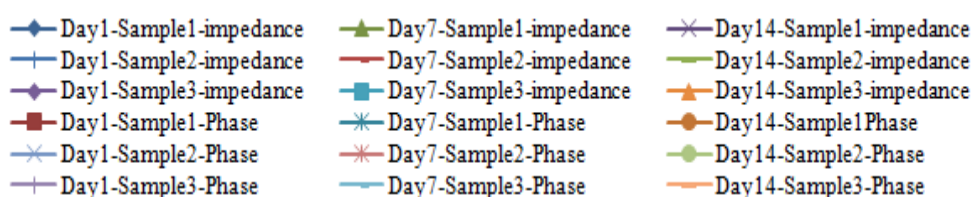


Figure 11: Common legend for the Bode plots of six coatings

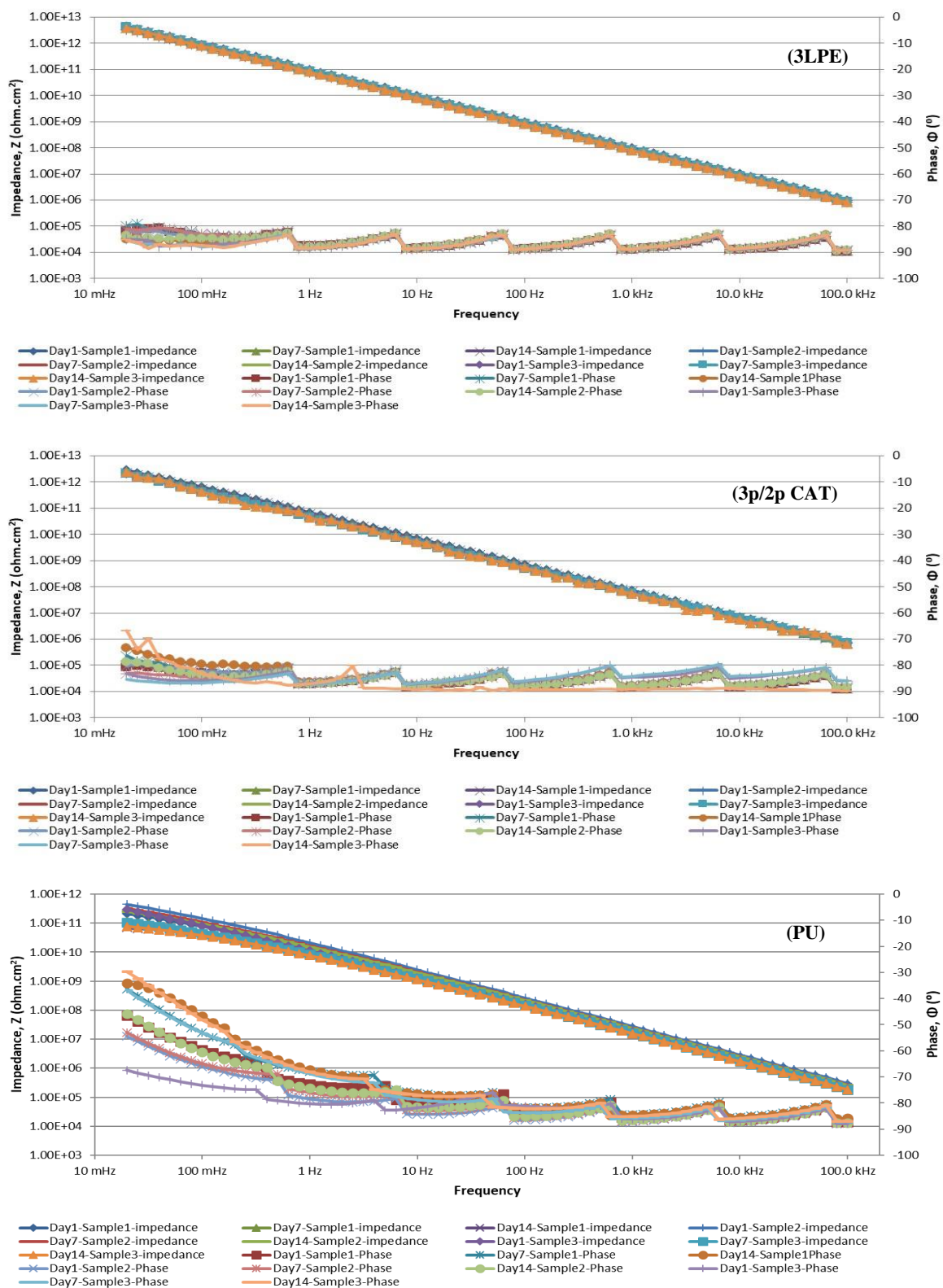


Figure 12: Bode plots of 3LPE, 3p/2p CAT and PU.

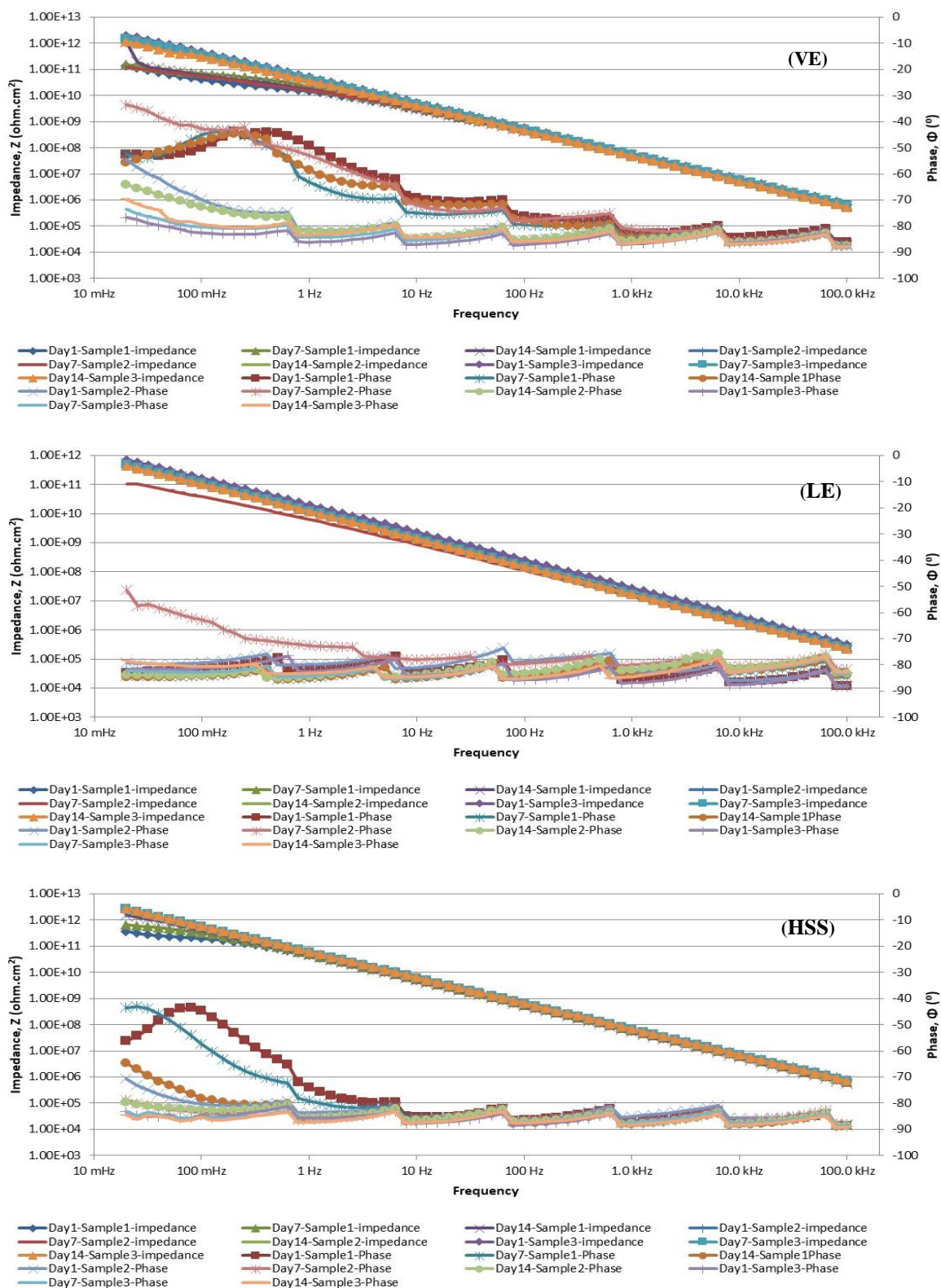


Figure 13: Bode plots of VE, LE and HSS

To distinguish the performances of six types of coatings, a comparison has been drawn based on the impedance values concerning cell areas of 1 cm² with

an applied AC voltage of 100 mV_{rms} in amplitude at a frequency of 100 mHz (0.1 Hz) versus 14 days of immersion in 3.5 % NaCl solution at 23-25 °C [29] and

is shown in Figure 14. It is apparent from Figure 14 that 3LPE has the highest impedance value. Compared with other coatings, 3LPE has shown better impedance properties than 3p/2p CAT, which is better than HSS. Therefore, the ranking of six types of coatings concerning their performances in EIS testing is found to be 3LPE-1, 3p/2p CAT-2, HSS-3, VE-4, LE-5, and PU-6, where '1' represents the highest performance.

EIS results usually demonstrate that for the same coating type, the coating impedance increases with increasing coating thickness [30]. But, in this study when a comparison of coatings performances has been made, a linear. Relationship between coating impedance and coating thickness is not observed.

The ranking of the coatings from SEIR and EIS tests have been analyzed to determine an overall ranking, as shown in Table 4.

If the overall ranking is compared to the suitability of use, where the coating performs well in both SEIR and EIS tests, 3LPE is best suited for buried SS316L pipelines.

There may be two opinions for the second best coating, where the suitability factor is the same for 3p/2p CAT and PU. Some industries give more importance to EIS over SEIR because EIS measures impedance and capacitance quantitatively and provides information on the electrochemical and corrosion processes of the coating and metal substrate beneath

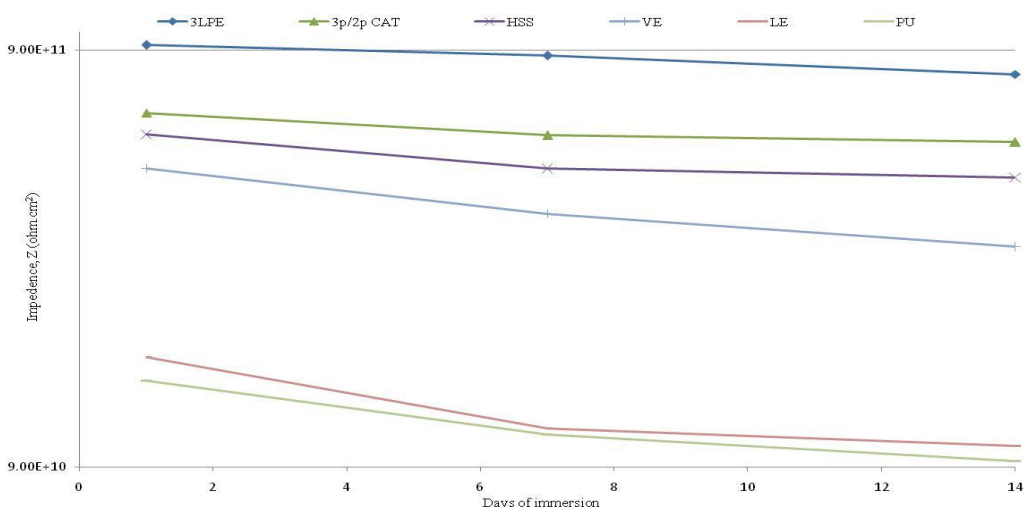


Figure 14: A comparison of impedance values of six coatings with respect to cell areas of 1 cm² with an applied AC voltage of 100 mVrms at 100 mHz for 14 days of immersion in 3.5 % NaCl solution at 23-25 °C.

Table 4: Overall ranking of six coatings.

Type of coating	Order of ranking		Suitability factor (arithmetic mean of standing)	Overall ranking (Note-A)
	SEIR test	EIS test		
3LPE	2	1	1.5	1
3p/2p CAT	5	2	3.5	2(Note-B)
PU	1	6	3.5	2 (Note-B)
VE	4	4	4.0	4(Note-B)
LE	3	5	4.0	4(Note-B)
HSS	6	3	4.5	6

Note-A: overall ranking “1” represents the highest performance

Note-B: overall ranking in preference to either the EIS test or SEIR test

the coating for pipelines buried in soil or submerged in water. For them, 3p/2p CAT is ranked second, and PU is third. Some other industries prefer to SEIR over EIS because SEIR measures quantitatively the net specific electrical insulation resistance of the coating for pipelines buried in soil or submerged in water. PU is ranked second for them, and 3p/2p CAT is third.

In line with the above reasoning behind 3p/2p CAT and PU, the overall ranking of VE and LE coatings are found to be either fourth or fifth, with the same suitability factor. Lastly, HSS is found to be in the sixth rank.

4. Conclusions

The experimental data collected from SEIR and EIS tests have been evaluated for the suitability of the coating for buried SS316L pipelines. It appears that 3LPE is best suited among the coatings. Other coatings used in the petroleum, petrochemical, and natural gas industries differ in opinion. Some industries prefer EIS over SEIR because EIS measures impedance and capacitance quantitatively and provides information on

the electrochemical and corrosion processes of the coating and metal substrate beneath the coating. According to EIS, 3p/2p CAT is better than PU. Some other industries prefer SEIR over EIS because of the simplicity of the SEIR test, and the data collected from the SEIR test are easy to interpret the electrical insulation resistance properties of the coating. Under SEIR, PU is better than 3p/2p CAT. In brief, the present study has revealed that 3LPE is the best coating, and barring 3LPE, 3p/2p CAT & PU are better coatings for buried SS316L pipelines in the petroleum, petrochemical, and natural gas industries.

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