



APPLIED GRAPHENE MATERIALS

TECHNICAL APPLICATION NOTE

Anti-Corrosion Primers: Part 5 Graphene Use in a Tiecoat System

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1. Introduction

Applied Graphene Materials UK Ltd (AGM) manufacture graphene nanoplatelets (GNPs) using a proprietary and patented process developed at Durham University in the UK.

AGM have developed significant in-house knowledge on the behaviour and performance of graphene modified coating formulations. These guidance notes are designed to provide formulation insights to assist development scientists achieve a technical appreciation of this novel technology, as well as accelerating the product development cycle.

The addition of graphene alone by a **Genable** dispersion introduced into coating formulations has demonstrated excellent barrier properties leading to a reduction in water vapour transmission rates (WVTR). This reduction in WVTR significantly enhances the anti-corrosion performance of an epoxy coating. (This improvement is discussed in more detail in AGM's Technical Application Note on Anti-Corrosion Primers: Part 1.). We have also shown that the **Genable** range in conjunction with non-metallic anti-corrosion additives can provide a more environmentally friendly alternative for protection (AGM's Technical Application Note on Anti-Corrosion Primers: Part 2).

2. Protective Coatings for Harsh Environments

Protection of metal infrastructure from corrosion is essential in preventing damage to the integrity of the structure which lead to costly repairs, increasing the potential for major structural failure and even risk to human life. Current organic industrial coating systems designed for harsh, high corrosion risk environments typically comprise of a number of different types of layers, each providing a different set of properties. A basic system usually consists of three layers, a primer coat, an intermediate coat and a final topcoat. The primer coats are typified by epoxy-based formulations containing a relatively high loading of an anodic metal such as zinc (e.g. zinc-rich primers), which provides a sacrificial protection to the metal substrate. Intermediate coats are usually formulated around a solvent/epoxy base with a pigment blend containing a relatively large fraction of micaceous iron oxide. The intermediate coat or tiecoat serves to promote adhesion between the primer coat and the topcoat layers. The tiecoat layer may also provide a barrier type protection against corrosive species such as water, ions or oxygen, slowing their diffusion to and from the metal surface, although it is recognized that there are some limitations to these barrier properties due to the permeability of these organic coatings to such corrosive species. Finally, the topcoat of the system normally comprises a pigmented polyurethane or polysiloxane systems that offer UV resistance in addition to the final colour and any other aesthetic finish.

A key protective component of these systems in harsh environments, where there is significant risk of corrosion, is the zinc-rich primer. These primers have been widely used since the 1930s for the protection of steel structures, by providing galvanic protection at edges or the places where the paint coating is defective. The superior performance of zinc rich primers was demonstrated in the FHWA-sponsored "PACE" study, where the zinc-rich primers performed best compared to other generic types of coatings evaluated under similar conditions¹. SSPC Paint 20 is an industry specification that categorises zinc primers according to vehicle types². Type II coatings are the most common involving organic vehicles such as epoxies and moisture cure urethanes.

The protection of steel by a zinc-rich coating is achieved mainly via two effects: the barrier effect imparted by the coating itself and by the galvanic action which the zinc particles in the coating provide. Three conditions are essential for the galvanic process to occur on steel:

1. Zinc particles must be in electrical contact with each other.
2. Zinc particles must be in electrical contact with the steel.
3. A continuous electrolyte must exist between the zinc particles and the steel.

The first two conditions are met by zinc-rich coatings when containing a sufficiently high zinc content. The third condition is fulfilled when a steel panel bearing a zinc-rich coating is wetted by a film of electrolyte such as a salt solution. The protective action of zinc-rich coatings may be broken down to two stages. The first stage is a relatively short period in which galvanic protection of the steel by zinc particles occurs. After this period in which the zinc is consumed, the galvanic action between the steel and zinc gradually disappears. The second stage is a long-term barrier protection that is attributed to (1) greater resistance of the coating to the permeation of aggressive species such as water, oxygen, and salts because the pores in the coating are blocked by the zinc corrosion products and (2) inhibition of the steel surface by the zinc corrosion products.

The attractive properties of graphene in its purest form as a single layer of graphite, have been talked about for many years. In addition to high mechanical and electrical properties, it has a high aspect ratio enabling the potential to function as an efficient barrier additive. When incorporated into an organic coating system or host matrix, the graphene nanoplatelet (GNP) form of graphene can offer a highly tortuous pathway that acts to impede the movement of corrosive species towards the metal surface³ - a passive corrosion protection mechanism. In addition, very small additions of GNPs decrease water vapour transmission rates,⁴ indicating a barrier type property, while some authors also suggest an electrochemical activity provided by graphene within coatings.⁵

3. Corrosion Evaluation

The efficiency of zinc-rich primers depends on several factors: zinc loading, effect of particle size and binder type⁶. The use of graphene nanoplatelets in combination with zinc has been proposed for use in zinc-rich primers and has been shown to impart a range of effects, depending principally upon loading level⁷. The objective of the work in this Technical Application Note was to evaluate how graphene enhanced tie coats can extend the life of the underlying zinc-rich primer. Graphene in this case does not act as an active anti-corrosive pigment but forms a passive barrier to water transmission within the coating. By addition of graphene to the tiecoat it is anticipated that water uptake and transmission through the film will be slowed, in essence protecting the zinc-rich layer. As a result, we envisage an extension in the service life of the coating, reducing the number of re-coats over the life of the substrate, and reduction of VOCs and the environmental impact associated with sacrificial zinc barrier properties in the intermediate layer.

3.1. Typical Graphene Based Primer Formulation

The evaluation was conducted using the graphene-based primer formulations described below (**Table 1**). For information relating to our standard dispersion please refer to the relevant product Technical Datasheets available at

<https://www.appliedgraphenematerials.com/products/knowledge-base/>

		Item	Raw Material Name	Weight %			
				Control	Genable 1000	Genable 1200	Genable 3000
Charged	{	Charge items 1,2,3 mix at high speed (1000 rpm) for 5 minutes					
		1	Epoxy Resin (EEW= 190g/eq.)	15.119	15.119	15.119	15.119
		2	Cymel U-216-8	0.244	0.244	0.244	0.244
		3	Anti-terra U	0.402	0.402	0.402	0.402
Grind	{	Add 4 and 5 mix at 1000rpm, then 3000rpm until grind <30um					
		4	Lake Chemicals R-216	10.966	10.966	10.966	10.966
		5	Rakem EWO Barytes	43.619	43.619	43.619	43.619
		Add 7 and mix at 3000rpm for 5 minutes					
		7	Tixogel MP	0.366	0.366	0.366	0.366
Add solvent 8 and mix at 2000rpm for 5 minutes							
		8	Butanol	1.986	1.986	1.986	1.986
Add solvent 9, mixing at 2000rpm							
		9	Xylene	15.376	15.376	15.376	15.376
Check mixture is homogenous and free of bits. Continue mixing if not.							
Add items 10 or 11. Mix at 2000rpm for 15 minutes.							
		10	Genable dispersion addition	0	10	10	10
		11	Epoxy resin (EEW=190g/eq)	10	0	0	0
Prior to application – Add item 12 and hand mix for 5 mins							
		12	Epikure 3223	1.922	1.922	1.922	1.922
			Total	100.00	100.00	100.00	100.00

Table 1 – Table of formulations used in this study

The epoxy to hardener mix ratio can be calculated for an appropriate hardener based upon the EEW and AHEW values. In this study, Epikure 3223 was used as the curing agent added at a rate of 11 parts per hundred of resin.

The following four tiecoats were used in the range of testing configurations summarised in Table 5.

Systems tested	GNP (%w/w)	Active (%w/w)	PVC (%)	VOC (g/L)	Stoichiometry
Blank Epoxy Prototype	0	0	29	262	85%
Genable 1000 Epoxy Prototype	1	0	35	262	85%
Genable 1200 Epoxy Prototype	0.1	0	37	240	85%
Genable 3000 Epoxy Prototype	0.5	0.9	35	253	85%

Table 2 – Tie Coat layer Formulation Parameters

Information on the commercial zinc rich primer and polyurethane topcoat is summarised in the table below.

	Chemistry	Volume Solids	VOC	Recommended DFT
Zinc Rich Primer (ZRP)	Epoxy Zinc Rich	59%	336g/l	50-75um
Polyurethane Topcoat (PU)	Aliphatic polyurethane	57%	420g/l	50-75um

Table 3 – Commercial primer and topcoat details

3.2. Manufacturing Guidelines for Anti-Corrosion Coating

The starting point formulations outlined above illustrate how the **Genable** graphene dispersions can be introduced directly into the resin formulation. The dispersions are typically introduced into the formulations at the let-down stage.

For further guidance, please contact our Business Development team using the included contact details.

3.3. Test Panel Preparation

Prior to application, all substrates were cleaned and degreased using acetone. Each first coat was applied to grit blasted mild steel CR4 grade panels, of dimensions 150 x 100 x 4mm, by means of gravity fed conventional spray gun, with all the panels cured for a period of 7 days at 24±°C. DFTs were in the specified µm range. Details are set out in **Table 4** below. The configuration of the panels using the four different tiecoats is shown in **Table 5**.

Substrate	CR4 Steel
Dimensions	150mm by 100mm by 4mm
Preparation	Grit blasting to SA2-1/2 rolled by degreasing with acetone
Application	Spray application (gravity-fed gun)
Coating Thickness	DFT 160+/- 20um ZRP typical thickness – 50um Epoxy Tiecoat – 60um Topcoat – 50um
Curing	7 Days at Room Temperature

Table 4 – Panel details and application

Designation	1st Coat	2nd Coat	3rd Coat
ZRP/Control/PU	Zinc Rich Primer (Commercial)	Control tiecoat formulation	Polyurethane Topcoat
ZRP/G1000/PU	Zinc Rich Primer (Commercial)	Genable 1000 tiecoat	Polyurethane Topcoat
ZRP/G1200/PU	Zinc Rich Primer (Commercial)	Genable 1200 tiecoat	Polyurethane Topcoat
ZRP/G3000/PU	Zinc Rich Primer (Commercial)	Genable 3000 tiecoat	Polyurethane Topcoat

Table 5 – Coating layers

3.4. Testing Protocol

Accelerated exposure: Neutral Salt Spray (NSS) - ISO 9227
Electrochemical Impedance Spectroscopy (EIS)

Panels were tested using a dual approach that combines NSS with EIS testing. Panels were prepared as detailed in **Table 5**. After the 7-day cure schedule (after application of the last coat), initial measurements were taken on EIS, after which, samples were put on NSS for intervals, detailed in **Figure 1**, and EIS measurements taken after each interval.

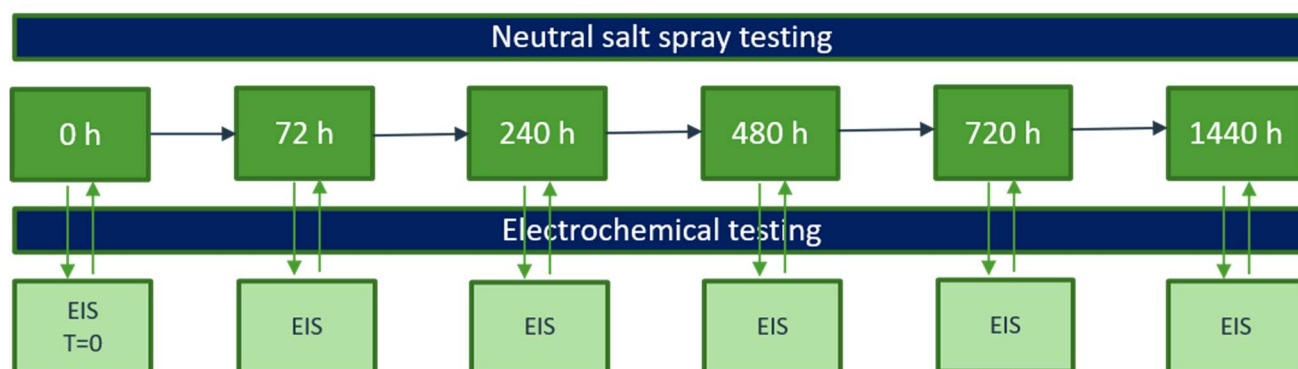


Figure 1 – Description of our combined NSS/EIS test method

4. Electrochemical Impedance Spectroscopy

4.1. Method

Prior to electrochemical/NSS testing, a small amount of the panel backing material was removed with a knife blade to provide an electrical connection point for the working electrode connectors. Upon completion of electrochemical testing, the removed section of backing material was covered with electrical insulation tape to reduce any possibility of corrosion whilst the sample was under NSS conditions. An additional prior step was to mark out the test area with a permanent marker to aid in relocating the test area for subsequent electrochemical measurements.

All electrochemical measurements were recorded using a Gamry 1000E potentiostat in conjunction with a Gamry ECM8 multiplexer to permit the concurrent testing of up to 8 samples per run. Each individual channel was connected to a Gamry PCT-1 paint test cell, specifically designed for the electrochemical testing of coated metal substrates.

Within each paint test cell, a conventional three-electrode system, the coated steel samples represented the working electrodes, a graphite rod served as a counter electrode and a saturated calomel electrode (SCE) served as the reference electrode. The test area of the working electrode was 14.6 cm². All tests were run using a 3.5 wt.% NaCl electrolyte. Electrochemical measurements consisted of corrosion potential measurements, E_{corr} , followed by electrochemical AC impedance spectroscopy (EIS) measurements.

During all EIS experiments, an AC voltage of 10 mV was applied across the sample, with a zero volt DC bias, over a frequency range of 1 MHz to 0.05 Hz. Ten measurements were recorded for every decade in frequency. An integration time of 1 second per measurement was used with a delay time of 0.2 seconds between each measurement. Equivalent circuit fitting to the obtained data was performed using the proprietary Gamry Echem Analyst software package in order to obtain coating capacitance values.

4.2. Impedance Measurements

When applied to the study of organic-based protective anti-corrosive coatings, impedance values provide an indication of corrosion protection⁸ as shown in **Table 6**. Such values may be used as an initial screening for coating barrier performance.

Figure 2 shows the progression of impedance modulus for the three coat systems tested, measured at 0.1 Hz, over the time period during which the samples were subjected to NSS conditions. Initial impedance values (recorded at $t=0$) range from the orders of 10^8 to 10^{10} $\Omega\cdot\text{cm}^2$. The control sample, consisting of a zinc-rich primer coat (ZRP), a layer of epoxy prototype base and polyurethane topcoat (PU), displays the lowest overall impedance values across the duration of the experiment. The lowest rate of impedance decrease is observed for the ZRP/G1200/ZRP graphene enhanced tie coat test configuration.

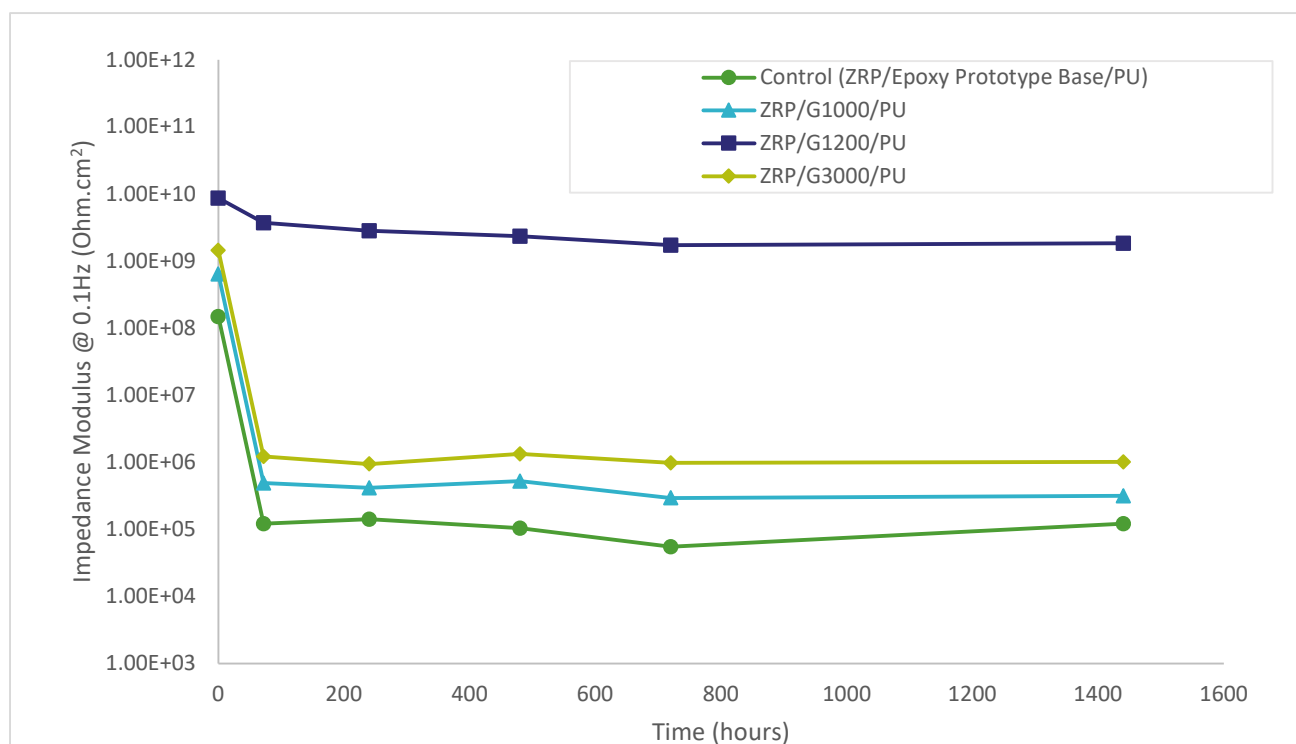


Figure 2 – Impedance Modulus Over NSS Exposure Time

Protection	Impedance @0.1 Hz (Ohm.cm ²)
Excellent	10 ¹⁰ – 10 ¹¹
Good	10 ⁸ – 10 ¹⁰
Protection Begins	10 ⁶ – 10 ⁸
Poor	Up to 10 ⁶

Table 6 – Impedance Protection zones

When different types of GNPs are introduced into the various intermediate layers of the coating, the impedance modulus is increased by varying degrees suggesting that the inclusion of a range of forms of GNP can act to progressively increase the barrier performance properties of the system as a whole.

A minimal increase in overall impedance is observed when **Genable 1000** dispersion is incorporated into the intermediate layer. In this case, the impedance is approximately one order of magnitude greater than the control when tested as a three-coat system. Incorporation of **Genable 3000** intermediate layer gave a final uplift of close to an order of magnitude above the control.

The **Genable 1200** intermediate layer, however, gave an uplift of five orders of magnitude above the control. In addition, the **Genable 1200** incorporated sample showed little change in impedance, compared to the other samples, during the course of the experiment. This suggests that the **Genable 1200** intermediate layer sample offers good to excellent barrier performance throughout the entire experiment, where the control ends in the middle of the poor impedance region (10⁴ Ω.cm²)⁸.

Coatings of relatively high thickness with superior barrier properties, such as those designed for use in C4/C5 type environments, will typically show high impedance, both at the onset of exposure and, ideally beyond, as the coatings are exposed to harsh environments for extended periods of

time. Coatings of lower performance, either due to a thinner application or inferior barrier properties, may also display a high impedance initially but will inevitably only last for a relatively short period of time before the impedance levels drop into the poor barrier performance region of the chart as defined in Table 6.

4.3. Water Uptake

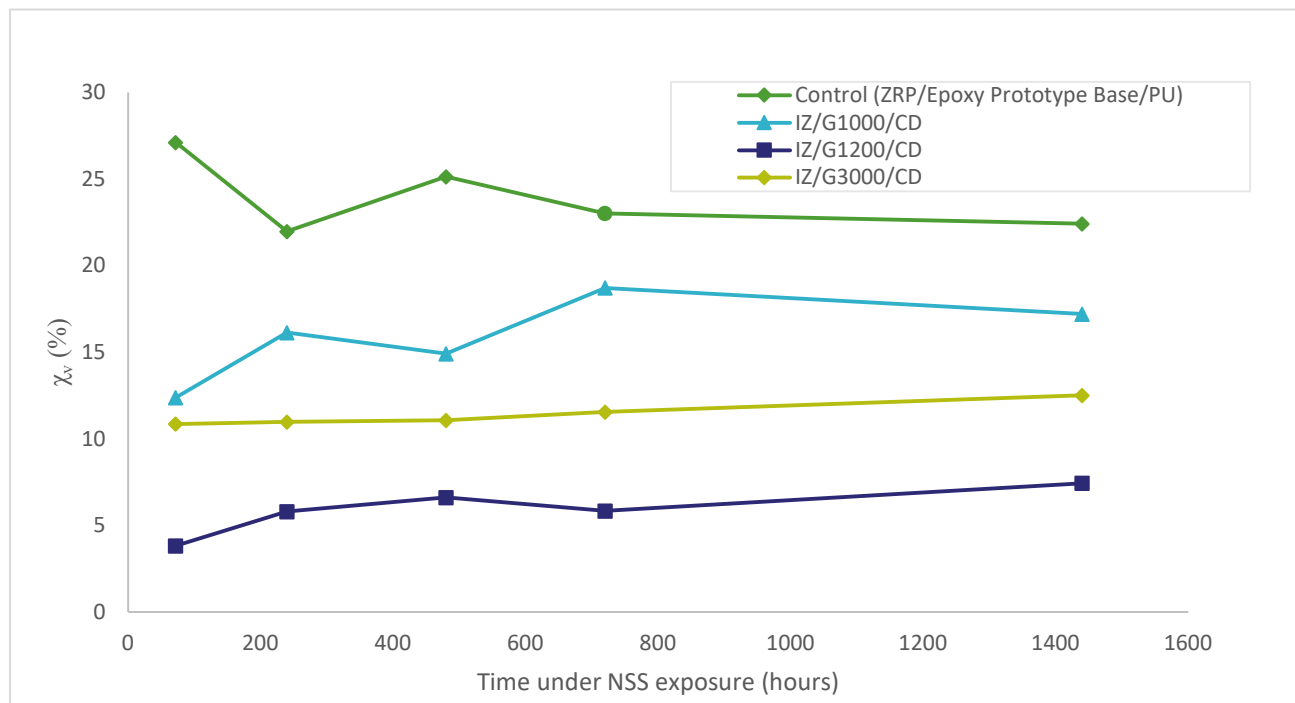


Figure 3 – Water content as volume percent

Water content as a volume percent, %v, within a coating may be calculated as:

$$\%v = 100 \frac{\log\left(\frac{1}{C_0}\right) / \left(\frac{1}{C_x}\right)}{\log(80)}$$

Where C_0 is the non-ideal coating capacitance at $T=0$ and C_x is the non-ideal coating capacitance at $T=72, 240, 480, 720$ and 1440 hours.

Figure 3 shows the water uptake values for the three coat systems, calculated from the coating capacitance values obtained from equivalent circuit fitting of the EIS data, as per the water uptake equation above⁹.

The control sample shows a relatively high water uptake, which is concordant with the relatively low impedance values for this sample. In comparison, the graphene enhanced tiecoat systems show far less water uptake, and appear stable during the test period; these low water uptake values reflect the relatively high impedance values for the graphene enhanced samples.

The results show that, as with the impedance results all the graphene containing system showed increased performance over the control. The **Genable 1000** system and the **Genable 3000** both reduced the water volume content within the coating by up to 50%. However, it was the **Genable 1200** system that was the best performer with a reduction in the water volume within the film of over 75% compared the control system.

4.4. Corrosion Potential (E_{corr})

The water uptake values show that whilst all the coatings absorb water, the systems with the graphene tiecoats absorbed less. It is, however, also important to understand how far into the coating this water has penetrated, and this can be demonstrated in the corrosion potential data (**Figure 4**).

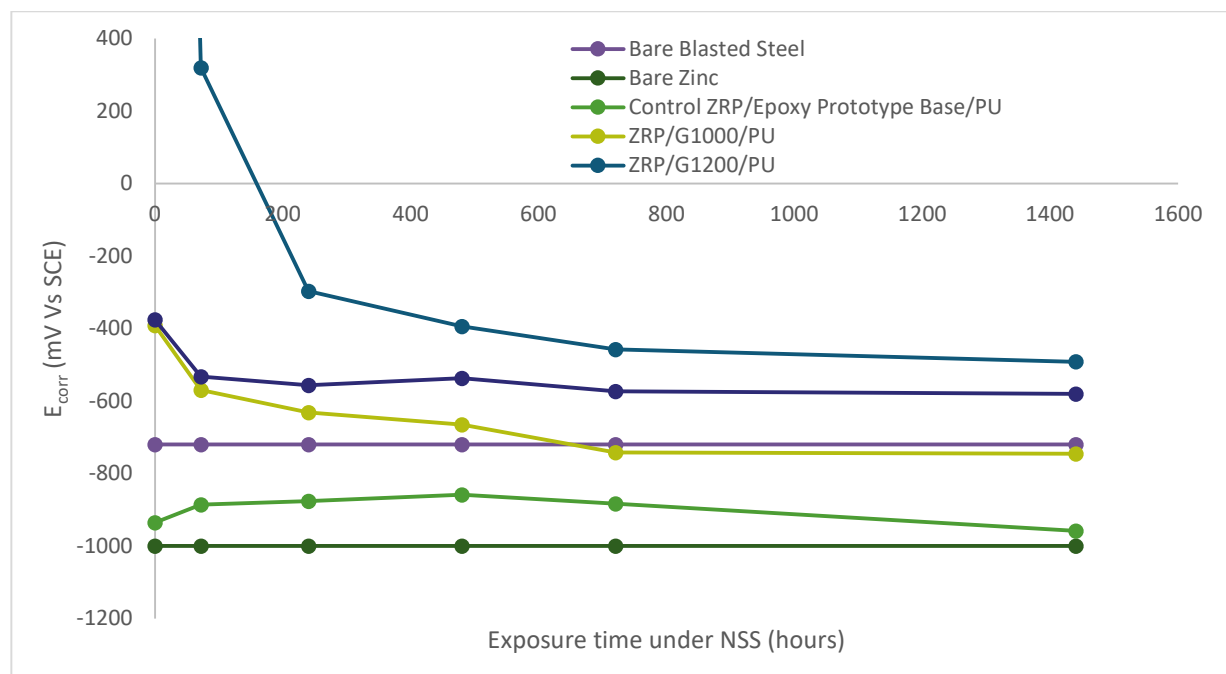


Figure 4 – Corrosion Potential

The control sample result shows a lower potential than bare steel, much closer to the potential for zinc metal, this suggesting that water has breached both the topcoat and the intermediate coat very early on in the test and reached the Zinc rich primer.

The **Genable 1000** sample performed well early in the test, although the potential started to drop increasingly after about 72rs and dipped slightly below the corrosion potential of bare steel after 720 hours, suggesting a lesser performance than the other two GNP-containing samples. The **Genable 3000** sample again performed well maintaining a good barrier performance. However, it was the **Genable 1200** system which performed the best.

4.5. Visual Panel Assessments – NSS Test

The 3 coat systems tested are based on commercial materials that have been developed to withstand many hours in harsh NSS environments. It was our expectation that visually, at the end of the test, we would not expect to see significant visual signs of corrosion on the panels.

After 1440 hours of exposure time, no visible corrosion was observed on any of the samples while creep results were less than 1 mm on all samples (**Table 7**). It is anticipated that, had we continued the NSS beyond 1440 hours, subsequent visual assessments would reveal differences between the samples, with more corrosion evident on the control sample.

The lack of visual signs of corrosion at this point in time highlights the relevance and potential importance of EIS, where clear differences in sample performance can be observed. The combined NSS/EIS tests are complimentary to each other since EIS can determine relatively small changes

within the coating e.g. with respect to water uptake prior to any visible coating changes noted from the examination of the test panels. The test conditions of NSS are more realistic and accelerative compared to simply submerging the sample in NaCl solution, under ambient conditions, as is usually done during prolonged EIS studies within the paint test cell. Test data from EIS and salt spray test results may also be used to corroborate coating performance.

1st Coat	2nd Coat	3rd Coat	Corrosion	Creep (mm)	Blistering
Zinc Rich Primer (Commercial)	Epoxy Prototype (No GNP)	Polyurethane Topcoat	No visible corrosion	<1	None
Zinc Rich Primer (Commercial)	Genable 1000	Polyurethane Topcoat	No visible corrosion	<1	None
Zinc Rich Primer (Commercial)	Genable 1200	Polyurethane Topcoat	No visible corrosion	<1	None
Zinc Rich Primer (Commercial)	Genable 3000	Polyurethane Topcoat	No visible corrosion	<1	None

Table 7- Neutral Salt Spray Corrosion

4.6. Double Layer Capacitance

In order to further examine the coated panels for evidence of electrolyte at the coating/substrate interface, equivalent circuit modelling was carried out on the impedance data relating to all coated panels. Interfacial electrolyte may give rise to a Helmholtz or electrical double layer. This electrostatic region is a source of charge density, which may be measured as a capacitance; the presence of a double layer capacitance indicates a full or partial breach of the coating, resulting in electrolyte at the substrate coating interface.

It was found that 2 different equivalent circuit models could be used to model the entirety of the impedance data, as depicted in **Figures 5** and **6**.

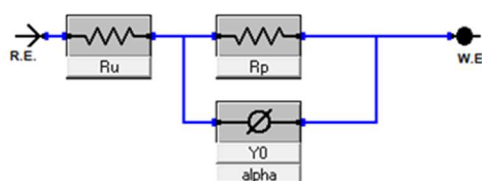


Figure 5 – Equivalent circuit model 1 – Initial model – Single time constant

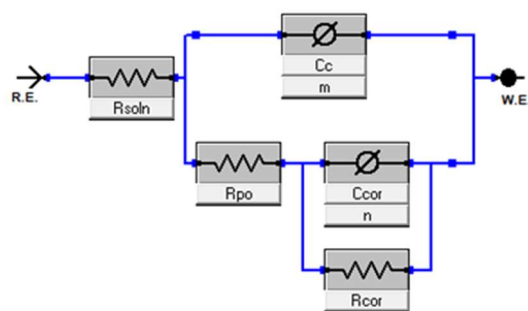


Figure 6 – Equivalent circuit model 2 – Later model including double layer CPE

The elements which make up this model 2 (**Figure 6**) include R_{soln} (the resistance of the electrolyte), C_c (coating capacitance), R_{po} (pore resistance), C_{cor} (double layer CPE) and R_{cor} (corrosion resistance). The coating capacitance and pore resistance elements are properties associated with the coating itself, whereas the double layer capacitance and corrosion resistance are both interfacial properties and exist when electrolyte meets the metal surface. Greater double layer CPE values indicate a larger presence of electrolyte at the interface, and, potentially, greater levels of corrosion.

It is typical to use a constant phase element (CPE) in place of a pure capacitor for the determination of double layer capacitance since such capacitive behavior often carries elements of non-ideality; the CPE is a more appropriate fit for such modeling.

Model 1 (**Figure 5**), a Randles type circuit, is essentially the same as model 2, but without the additional time constant (incorporating double layer CPE and corrosion resistance). Therefore, we would expect to use model 1 in cases where the coating hasn't been breached to any extent e.g. early on post NSS exposure, and use model 2 in cases where the coating has been breached.

Table 8 highlights the models used to fit the experimental data at all time points. For all samples, at $T=0$, model 1 was a more appropriate fit, suggesting no coating breach for all samples. From the first assessment at 72 hours, model 2 was found to be a more appropriate fit for all samples, aside from the **Genable 1200** sample.

For the **Genable 1200** sample, the change from model 1 to model 2 wasn't noted until the 720 NSS exposure time point. This suggests that the **Genable 1200** sample offers the best performance in respect of barrier protection, comfortably surpassing all other samples.

Time under NSS conditions (hours)	0	72	240	480	720	1440
Control (ZRP/Epoxy Prototype Base/PU)	Model 1	Model 2	Model 2	Model 2	Model 2	Model 2
ZRP/G1000/PU	Model 1	Model 2	Model 2	Model 2	Model 2	Model 2
ZRP/G1200/PU	Model 1	Model 1	Model 1	Model 1	Model 2	Model 2
ZRP/G3000/PU	Model 1	Model 2	Model 2	Model 2	Model 2	Model 2

Table 8– Outline of equivalent circuit model fitting to data over time

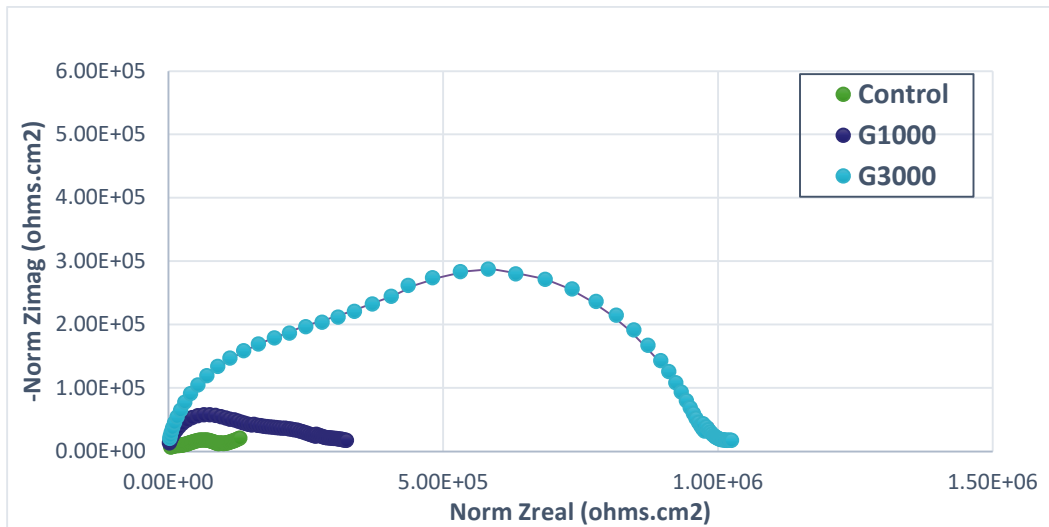
Figure 7 shows the complex or Nyquist impedance plots for all samples at 1440 hours NSS exposure. The Nyquist or complex plot is one means of displaying impedance data, where the data from each frequency point is plotted by the imaginary part (Zimag) on the y axis and the real part of the impedance on the x axis (Zreal). This type of plot is valuable for identifying how many characteristic features are exhibited by a system, and this may be noted by the shape of the plot. For example, a single time constant circuit consisting of a resistor and capacitor in parallel would be observed as a single semi-circle on a Nyquist plot. Adding a resistor in series with this circuit,

essentially now creating Model 1 (Figure 5), would show an offset semicircle, with the value of the offset equivalent to the value of the resistor, measured on the Zreal axis.

Figure 7(a) shows the complex plots for the control, **Genable 1000** and **Genable 3000** samples. Due to the much larger impedance values observed for the **Genable 1200** sample, the complex plot for the **Genable 1200** sample is shown on a different scale **Figure 7(b)**.

The span of the complex plots is reflected in the overall impedance values (Zreal and Zimag) previously shown, the control plot covers a relatively small span (lowest impedance) and the **Genable 1200** plot (of higher impedance) covers a much greater span. It is also clear that there is some difference in the shapes of the complex plots. All samples apart from the **Genable® 1200** sample share a similar form of 2 depressed semi-circles, the second semi-circle indicating the presence of the second time constant (incorporating double layer CPE and corrosion resistance), suggesting the presence of water at the interface is well established for these samples. Although there is a second time constant associated with the **Genable® 1200** sample, this is significantly less visible in the complex plot compared to all other samples, only appearing at the 720 hour point, suggesting a transition period between models 1 and 2, and a lower degree of electrolyte the interface.

(a)



(b)

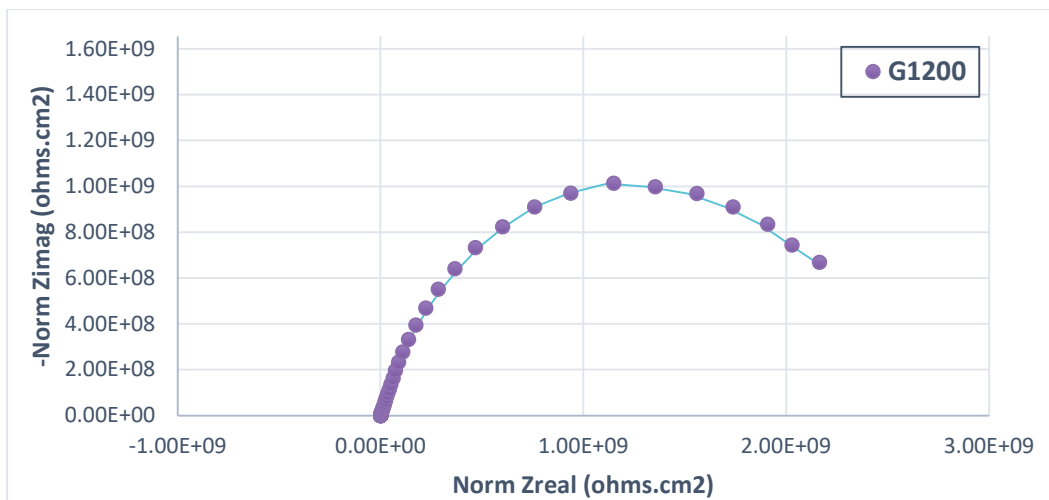


Figure 7 – Complex plots of impedance data for (a) control, G1000 and G3000 samples (b) G1200 sample at 1440 hours NSS exposure

Figure 8 shows the progression of the double layer CPE over the course of the experiment. Since the Model 2 equivalent circuits model, incorporating the double layer CPE time constant, is only employed at the 720 hour point for sample **Genable 1200**, the double layer CPE data is only available from 720 hour as this is the point at which electrolyte is present at the interface.

The **Genable 1200** sample also shows a very low and constant double layer CPE beyond the 720 hour mark, suggesting very little electrolyte is present at the interface, indicating a superior barrier performance. The **Genable 3000** sample also shows a relatively low double layer CPE value. The highest double layer CPE value is obtained from the control sample, suggesting a relatively poor barrier performance, despite acceptable visual performance.

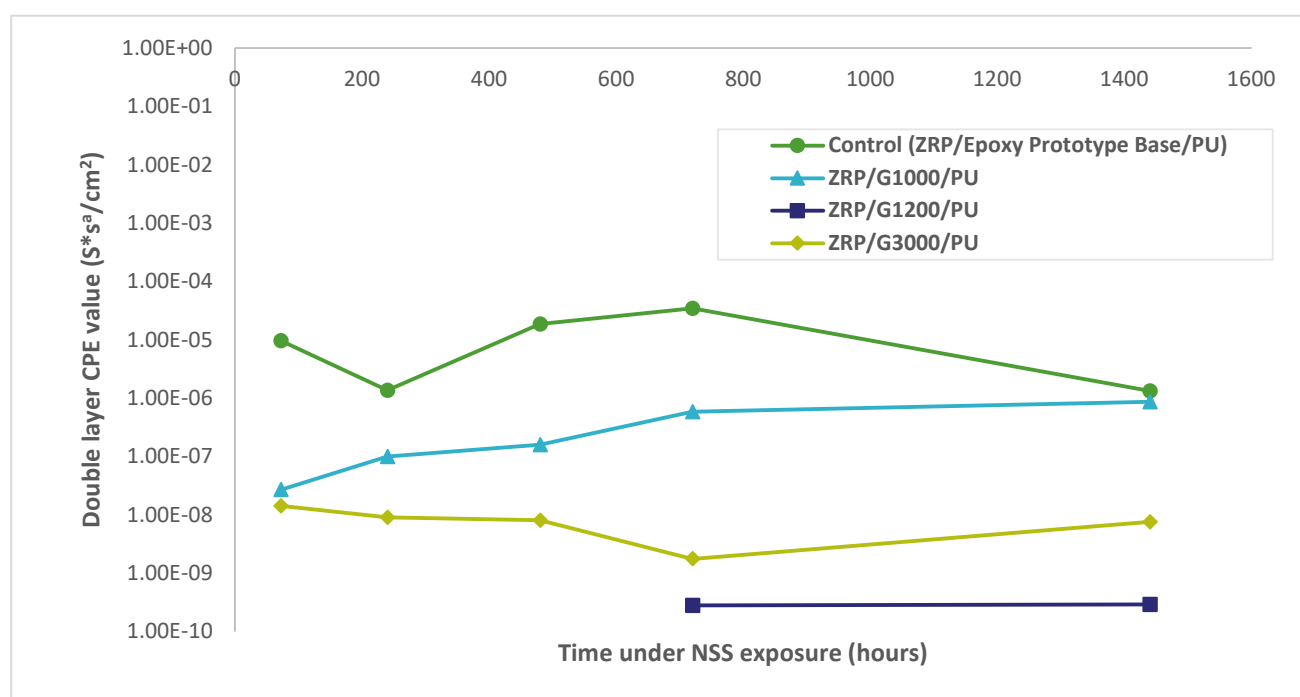


Figure 8 – Double layer CPE Vs time under NSS exposure for all samples

5. Technical Comments

Assessing whether Graphene in a tie coat can extend the life of a zinc rich primer

The aim of the work described in this Technical Application Note is to evaluate if graphene nanoplatelets in a tiecoat layer can enhance and extend the life of a commercially available zinc-rich primer in a three-layer system. Previously we have shown the synergistic benefits of using graphene in conjunction with a reduced level of zinc phosphate (AGM's Technical Application Note on Anti-Corrosion Primers: Part 1) as well as the performance uplift that can be achieved by using a more environmentally friendly alternative non-metallic inhibitors in combination with graphene nanoplatelets (AGM's Technical Application Note on Anti-Corrosion Primers: Part 2).

In this application note, we have shown that graphene can be used in a discrete intermediate barrier coating (tiecoat) to protect a zinc-rich primer, thus offering the potential to significantly extend life of the existing coating system, providing both economic and environmental benefits. Compared to the control intermediate layer formulation, the inclusion of graphene in the tiecoat shows a substantial improvement in anti-corrosion performance demonstrated by the EIS testing. These coating systems show a higher impedance and lower water uptake compared to the control coating, with **Genable 1200** system demonstrating the highest level of performance. These graphene-based tiecoats are acting as a water barrier thus extending the time it takes water to reach the zinc-rich primer and initiate the sacrificial reaction.

This study clearly demonstrates the benefit that graphene can bring to a protective tiecoat coating used in tandem with a zinc-rich primer system to improve performance and lifetime of the system. Introduction of a graphene-enhanced tiecoat offers a low-risk avenue to add a new technology that may enhance system performance in meeting C4/C5 ISO12944 type systems. For customers currently using a zinc-rich primer with a tiecoat and topcoat, substituting the tiecoat with a graphene intermediate in their system potentially offers many advantages, including extension of maintenance periods and thus reduced life cycle costs of the coating system. It also has the potential to offer several major environmental impact benefits, such as improving the global warming potential calculation and other life cycle analysis metrics through reduced demand for repair and recoating leading to a reduction in the release microplastics during surface preparation and repair. The overall release of the volatile organic materials into the atmosphere can also be reduced during the life time of the coated item as a consequence of a reduction in the number of maintenance activities.

For more information about our graphene nanoplatelet dispersions and their use or if you would like a sample of **Genable 1200** or any other of our products to test, please visit www.appliedgraphenematerials.com or contact us via email info@appliedgraphenematerials.com

6. References

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7. Contact Details

For further information, please contact the Business Development department using the following details:

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