



**APPLIED
GRAPHENE
MATERIALS**

Coatings

The New Anti- Corrosion Toolbox

2021

appliedgraphenematerials.com

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Corrosion Protection with AGM



- ⬡ What is **Graphene**?
- ⬡ What do **AGM** do?
- ⬡ How do AGM's **Genable[®] Dispersions** work?
- ⬡ The Toolbox to **Tackle Corrosion**



What is Graphene?

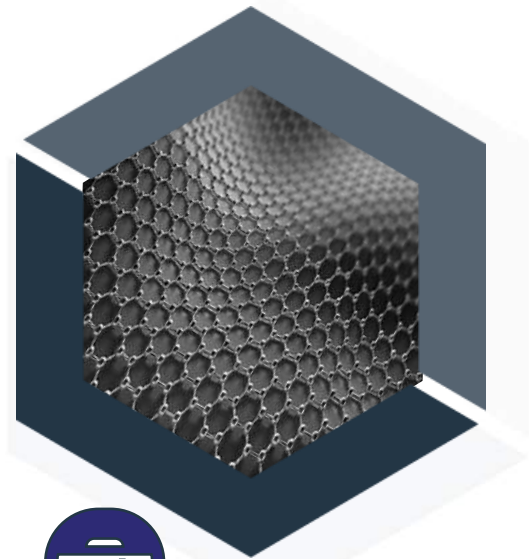
Pristine Graphene is a form of carbon consisting of planar sheets which are one atom thick, with the atoms arranged in a honeycomb-shaped lattice.



Best Conductor of Electricity



Thinnest and Lightest Materials Known



100x Stronger than Steel



“Perfect” Thermal Conductivity

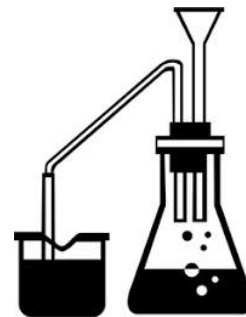
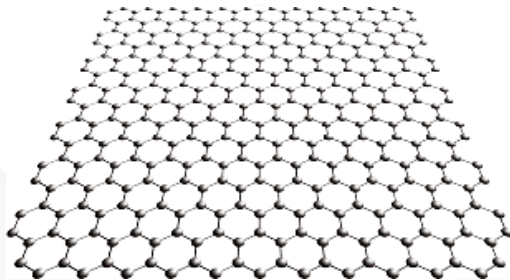
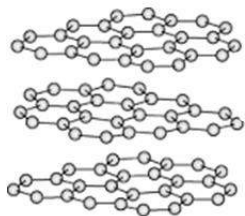


Completely Transparent



What is Graphene?

Methods of production of Graphene Nanoplatelets



Top Down

- ⬡ Mechanical or chemical exfoliation of Graphite
- ⬡ Often has relative high crystal quality
- ⬡ Graphite source - effects product can be contaminated by organic impurities
- ⬡ Difficult to control the number of graphene layers accurately

Bottom Up Synthesis

- ⬡ Produced by molecular growth from carbon precursors
- ⬡ Number of layers can be controlled using different substrate catalysts and growing/reaction parameters
- ⬡ Can gives large surface area and high purity products
- ⬡ Offers a high quality approach for mass production with consistent batch to batch multi layer Graphene



What do Applied Graphene Materials do?

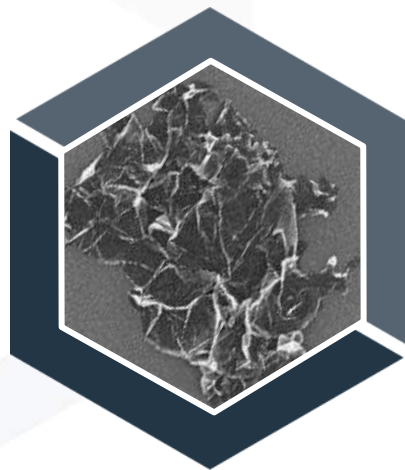
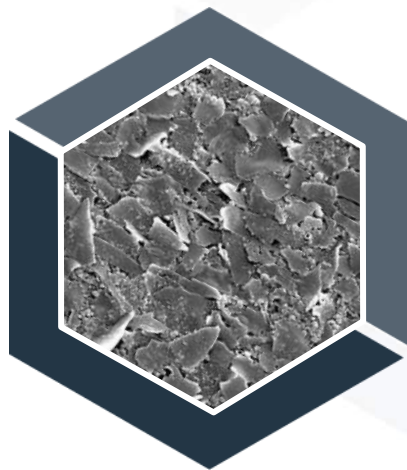
Production and Characterisation of Graphene Nanoplatelets



- AGM uses Patent-Protected technology to produce a range of Graphene Nanoplatelets (GNPs)

Reduced Graphene Oxide

- 15 – 20 Atomic Layers Thick
- 15% Oxygen Content



Graphene

- 3 – 5 Atomic Layers Thick
- 5% Oxygen Content

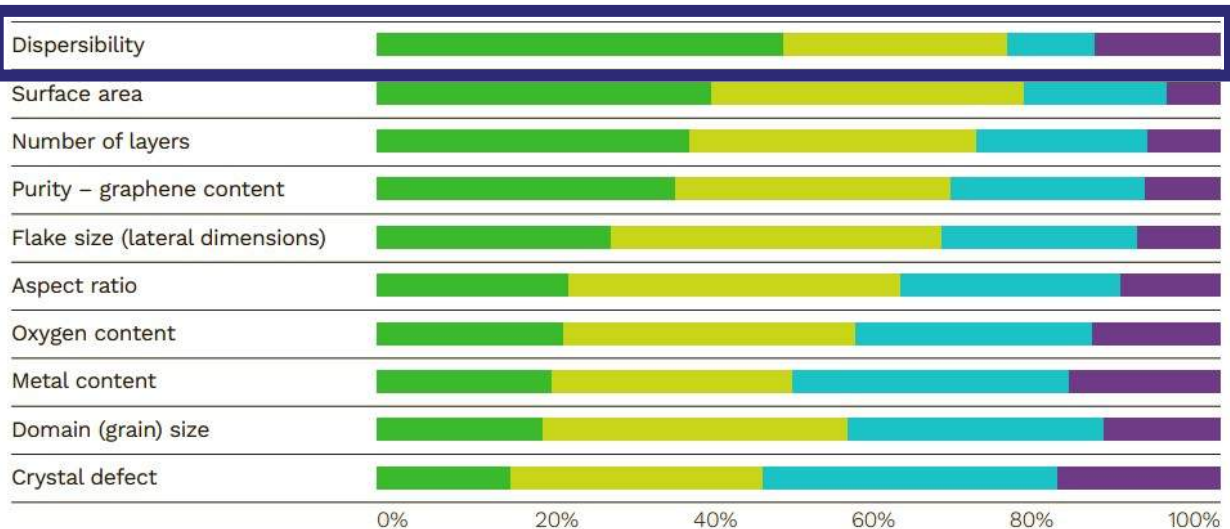


Leaders in Graphene Dispersion Technology



Deploying Graphene nanoplatelets

● Essential ● Important ● Interesting ● Not needed



“The **processing** and **handling** of graphene is integral to achieving success in an application”

“While graphene is widely available, it requires **expertise in handling**, working with experts with these skills is **critical**”

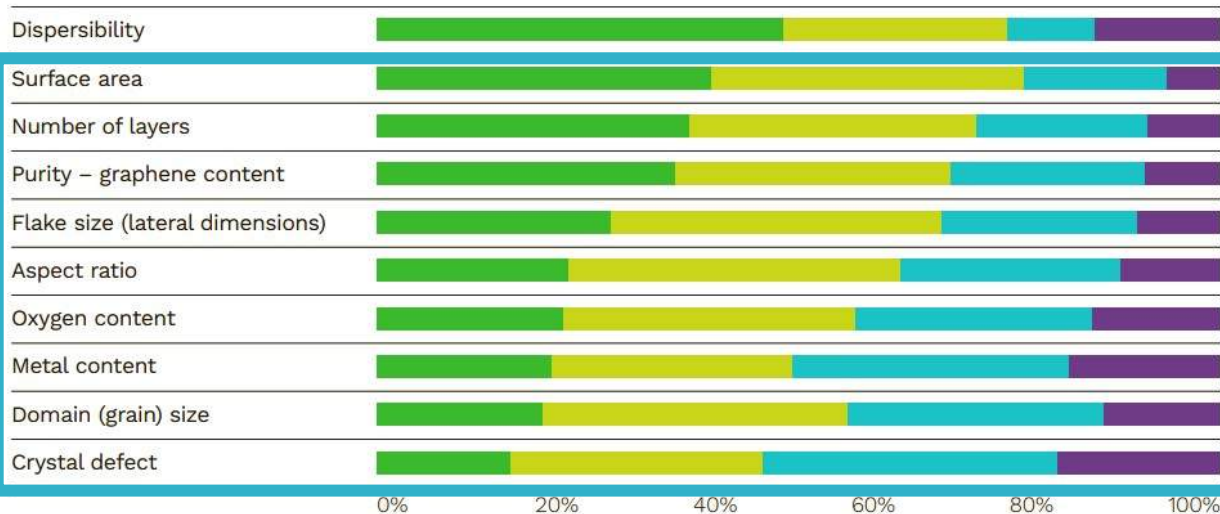
Reference: The Graphene Council Survey report 4 Jan 2021

Leaders in Graphene Dispersion Technology

Deploying Graphene nanoplatelets



● Essential ● Important ● Interesting ● Not needed



After dispersion – the other attributes are all about **consistency of quality** of the Graphene Nanoplatelet materials

The key to long term customer success = **consistent materials qualities / attributes**

Reference: The Graphene Council Survey report 4 Jan 2021

What do Applied Graphene Materials do?



Proud to be a leading innovator in graphene nanoplatelet dispersions and application technology



What do Applied Graphene Materials do?



Industry Leading Know-How in the Dispersion of GNPs...

AGM uses Patent-Protected technology to produce both the standard **Genable**® product ranges and custom dispersions to meet everyone's needs

- ⬡ **Easy to handle** and **incorporate** into existing industrial systems
- ⬡ **Long-term stability** of standard dispersion products
- ⬡ **Optimised dispersion** properties design for specific final application
- ⬡ **Enabling** industry to benefit from the potential of graphene in a simple, safe and easy to formulate way.



What our Genable® Dispersion can do?

Wide range of applications

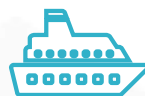
Anti-corrosion,
erosion, composites
in wind turbines



Satellite – Thermal
management and
low mass

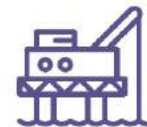


Aerospace performance
advantages for
composites



Anti-corrosion
and Chemical
Resistance for
marine

Aerospace –
Aluminium
corrosion
protection



Offshore harsh
environment
protective
coatings

Enhanced
Pipelines
coatings



Heat
management
potential



Infrastructure
– chemical
resistant floor
coatings



Replacement of poor
environmental

Transportation –
vehicle weight
reduction and anti-
corrosion plus
batteries



Anti-corrosion
/ Chemical
resistance –
industrial plant



Coatings for
Textiles



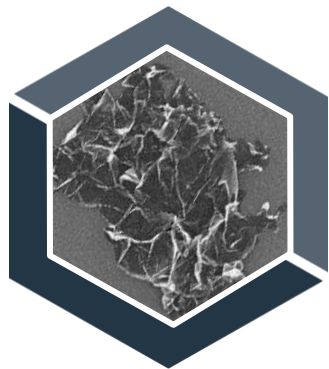
Battery and Thermal
conductivity for
Electrification of
Vehicles



Infrastructure –
better coatings for
roof, cladding,
building structure



How do Graphene Nanoplatelets Work?



1g of AGM Graphene powder
contains

11,200,000,000,000
individual particles

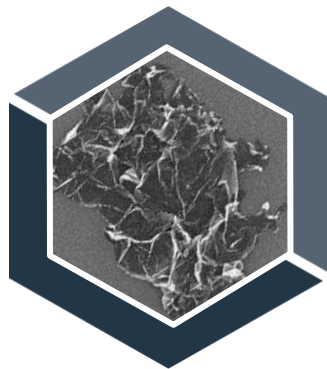
10g of AGM Graphene powder
would occupy a volume of **1**
litre

20g of AGM Graphene powder
has the equivalent surface area
of an entire football pitch



How do Graphene Nanoplatelets Work?

Comparison of Surface Area Against Mica Flake



The impact on the added surface area in **1kg** of industrial paint as a result of the incorporating...

...10% Mica Flake – 10m^2

...0.1% Graphene Nanoplatelets – **350m^2**

35x the Surface Area with **$1/100^{\text{th}}$** of the active material



How do Graphene Nanoplatelets Work?

Comparison of Tortuous Path Length Against Mica Flake



In a standard industrial paint applied at 150 μ m DFT...

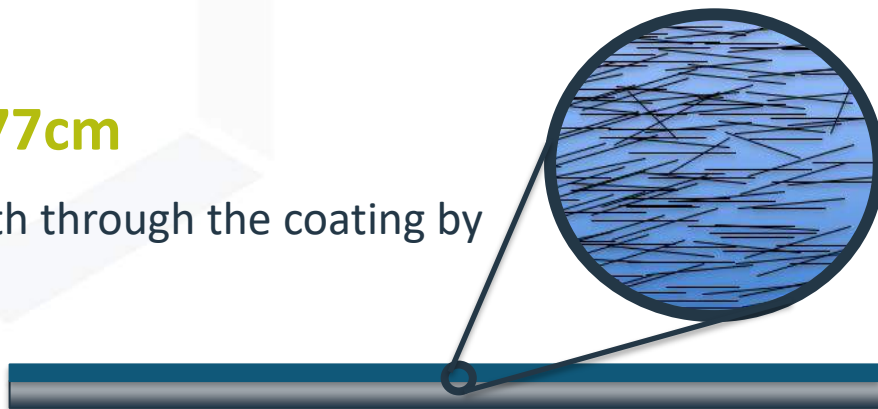
...with 10% mica flake – **0.103cm**

Therefore increasing the Tortuous Path length through the coating by **7 times**



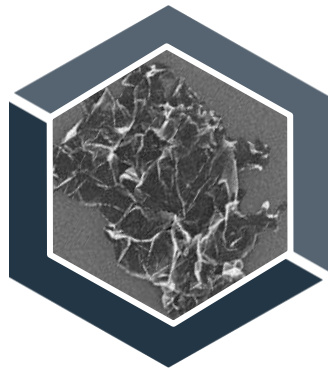
...with 0.1% Graphene Nanoplatelets – **1.777cm**

Therefore increasing the Tortuous Path length through the coating by **120 times**



How do Graphene Nanoplatelets Work?

Comparison of Tortuous Path Length Against Mica Flake



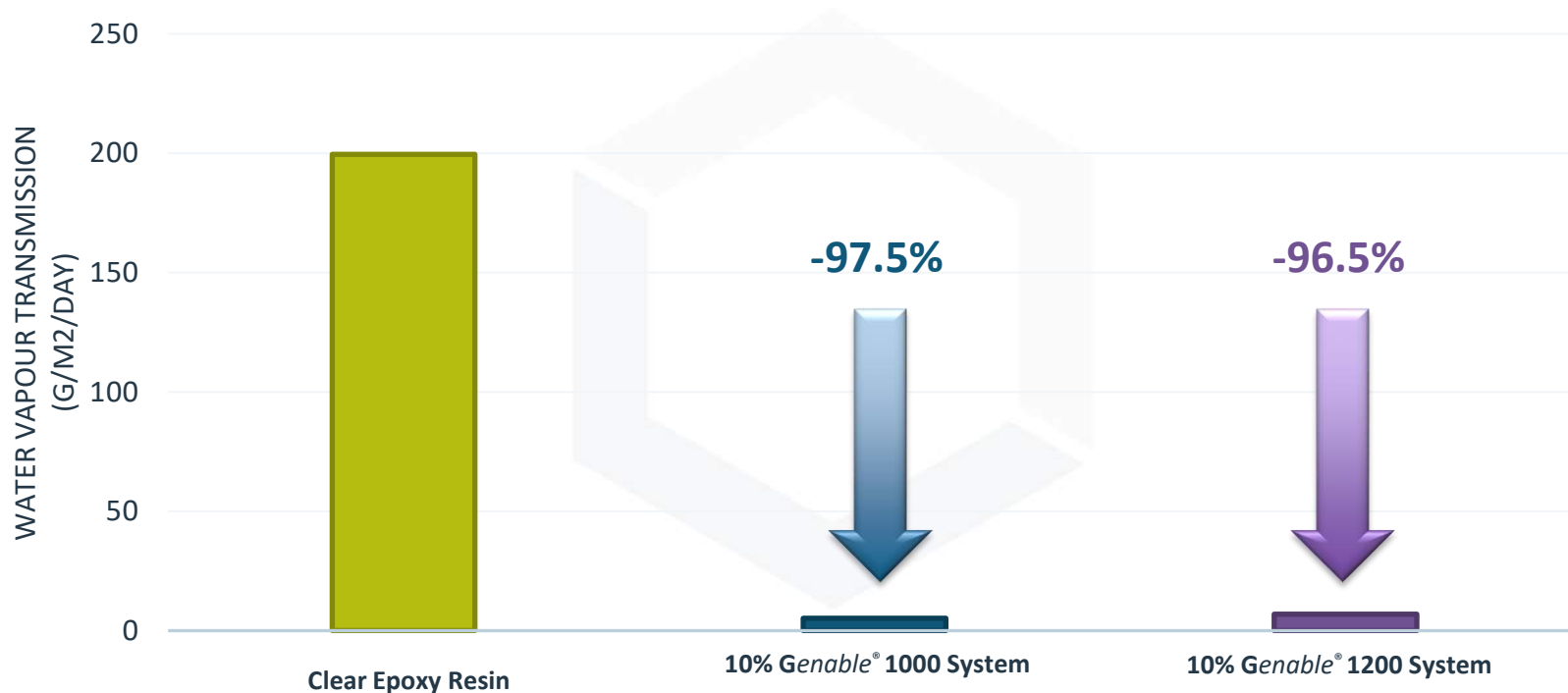
Compared to a typical Mica Flake with a particle thickness about **5 μm** ...

...AGMs Graphene Nanoplatelets are approximately **3000 times** thinner



What do Genable® Dispersions do?

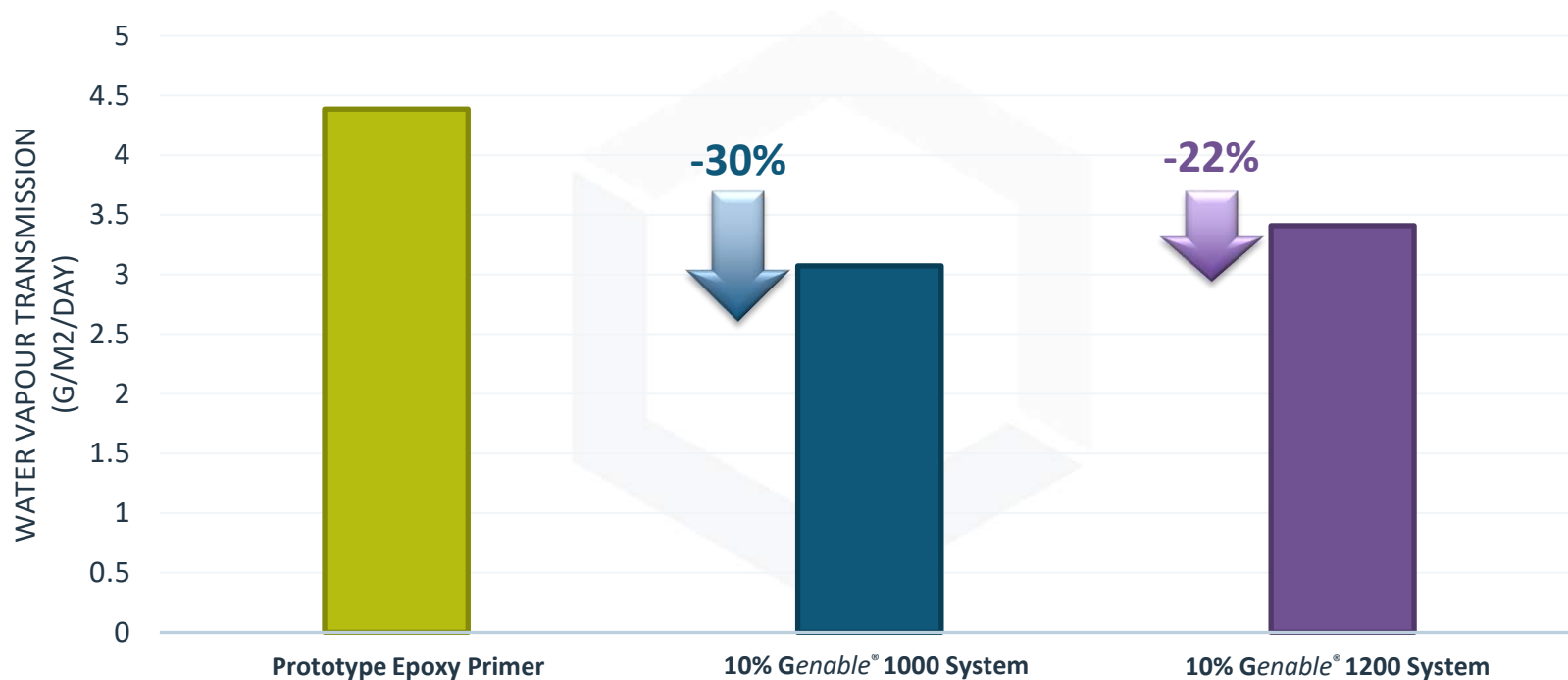
Water Vapour Transmission Analysis



What do Genable® Dispersions do?



Water Vapour Transmission Analysis

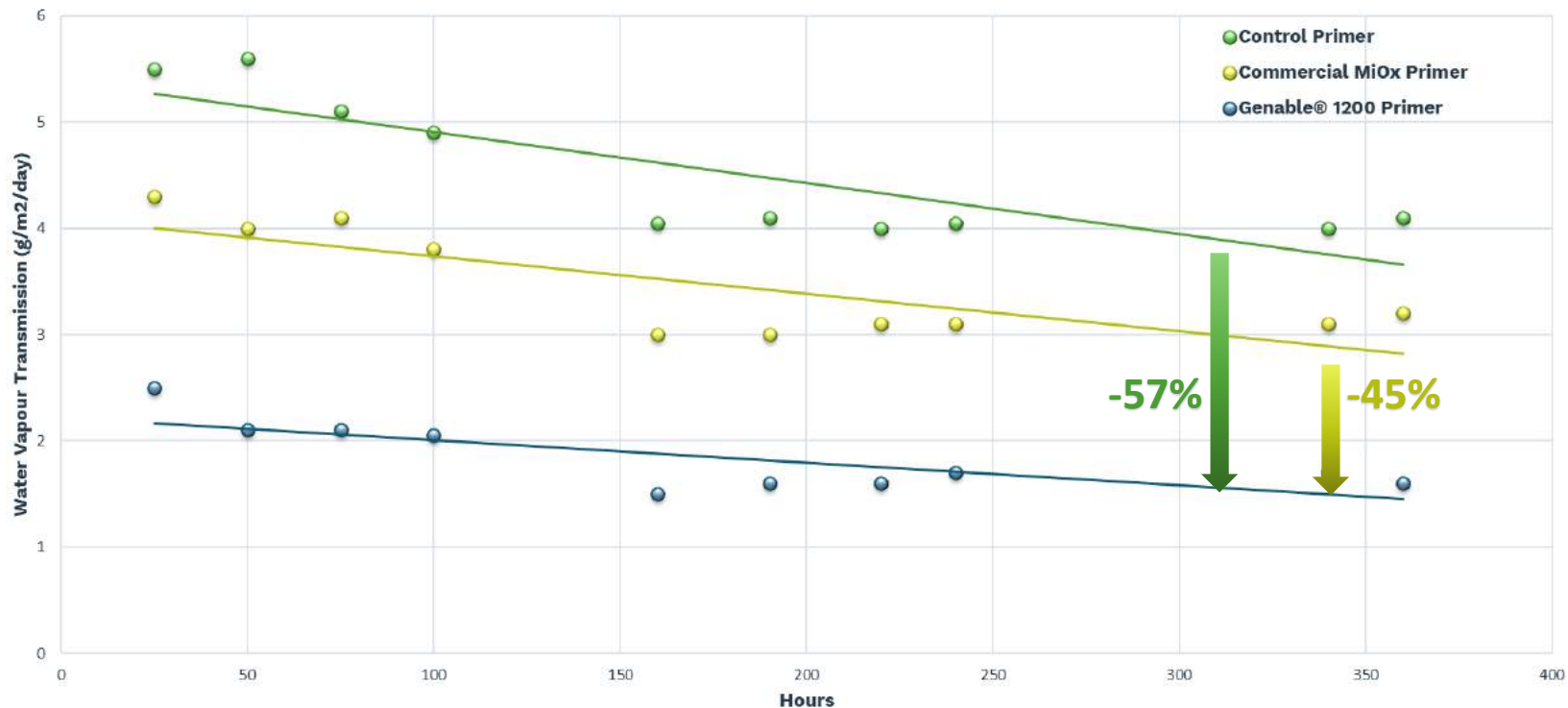


What do Genable® Dispersions do?



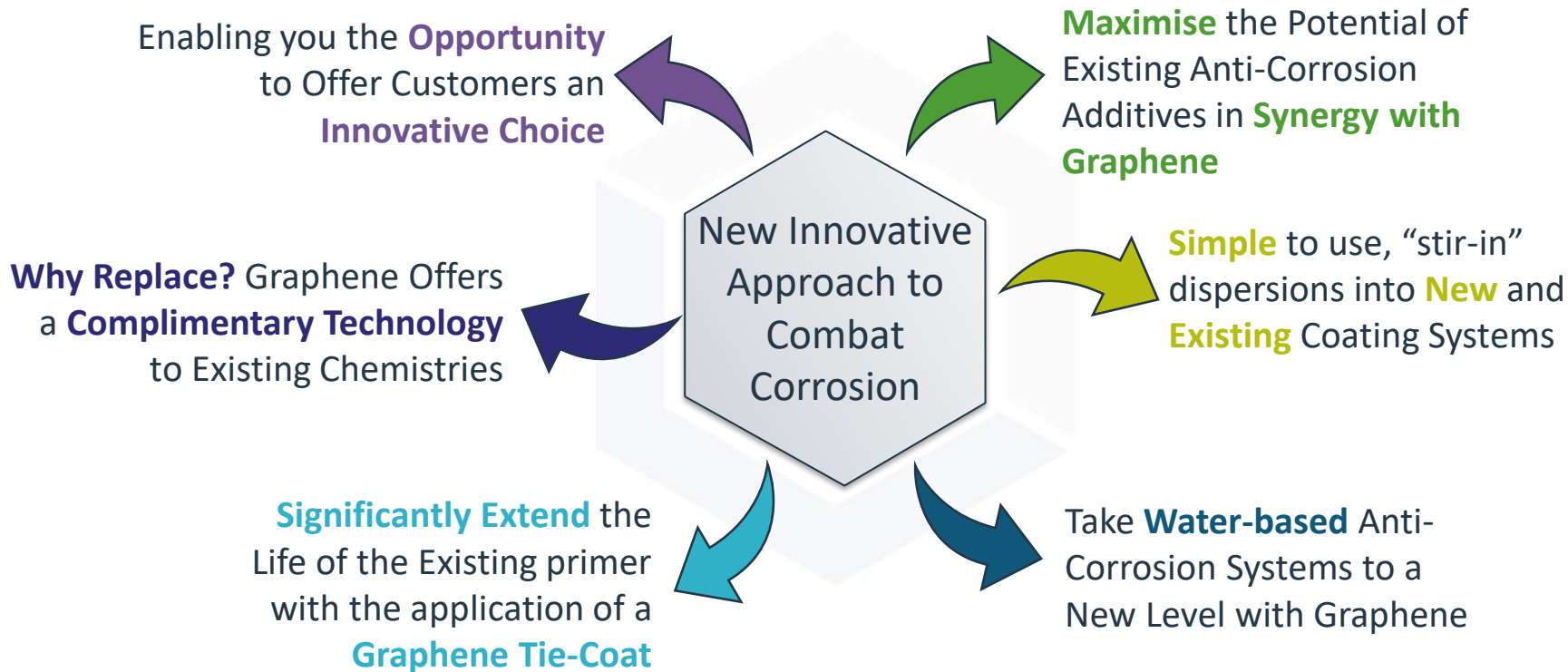
Water Vapour Transmission

Comparison Between Commercial MiOx and Graphene based Formulated Epoxy Primers



What do Genable® Dispersions do?

Innovate with AGM's **Genable®** dispersions – Creating Possibilities



The Toolbox to Tackle Corrosion



- ⬡ **Standalone** Corrosion Protection
- ⬡ The **Synergy** of Graphene with existing actives
- ⬡ **Tie-Coat** – Protect you Protection
- ⬡ **Water-Based** Anti-Corrosion Protection



Outstanding Corrosion Protection



Why **Innovate** with Graphene?

- Add a **complimentary** addition to the existing range of anti-corrosion products
- **Extend** the life of **existing coatings** with easy to incorporate dispersion – **simply add and stir**
- Offer your customers a **heavy metal free, environmentally friendly** alternative to Zinc based chemistry
- Add **value** for the coating innovator. Add **service life** to the coated asset. A true **Win-Win**



Outstanding Corrosion Protection

Neutral Salt Spray After 720 Hours



Zinc Phosphate Primer



Genable® 1200 Primer



Automotive Aerosol Primer Success Story



Customer identified an innovative way to improve their existing primer paint for automotive repair applications.

Current system is a basic vinyl/acrylic based paint with limited anticorrosion performance.

Applications are typically single coat with low film thicknesses.

Genable® dispersion tested at loading levels between 5% to 20% w/w on total formulation

Key Target Benefits:

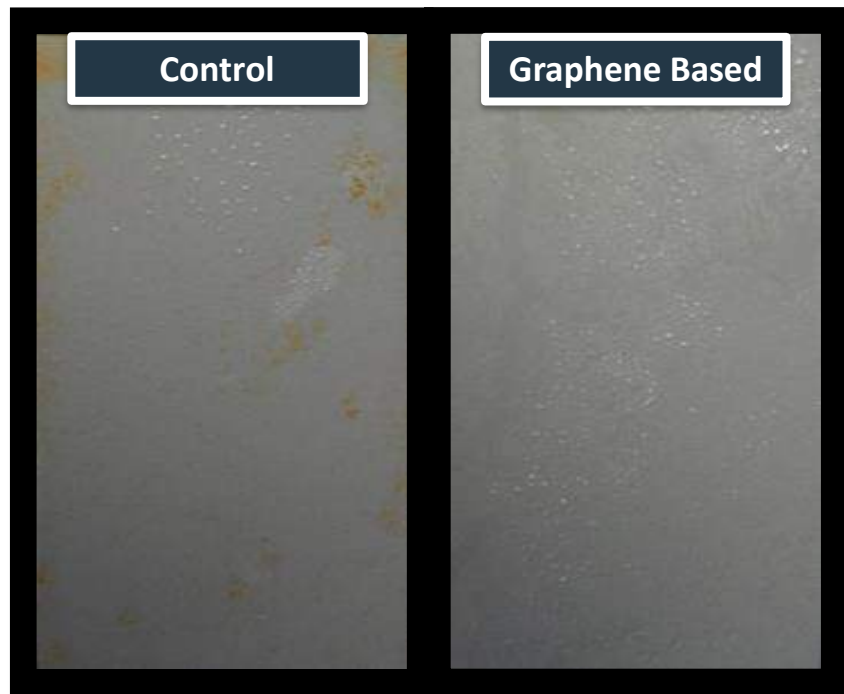
- **Significantly** improve corrosion performance
- **No impacting** on other physical properties
- Ensure the paint remains **economically viable** for consumer repair customers



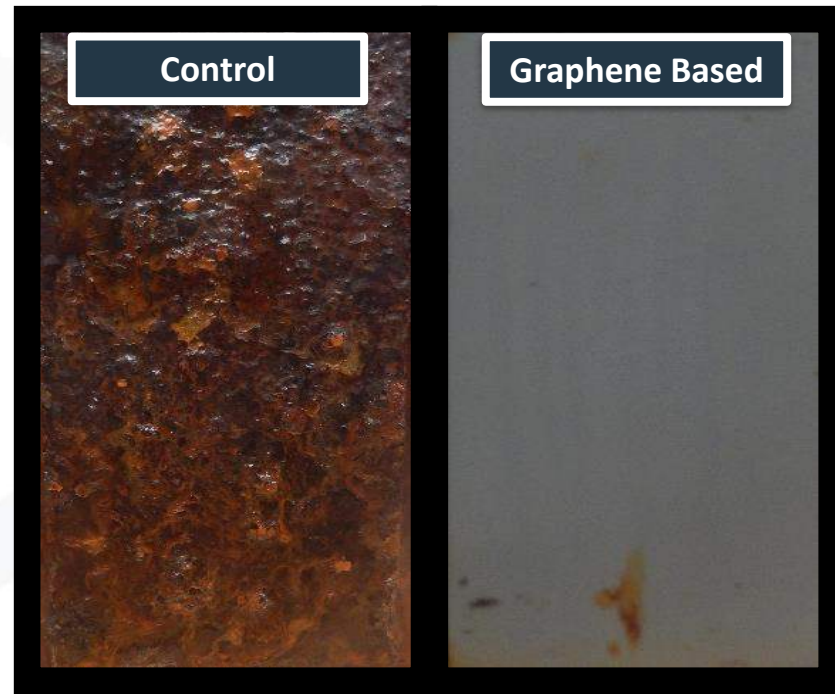
Automotive Aerosol Primer Success Story



Prohesion Salt Spray After **170 Hours**



Prohesion Salt Spray After **3000 Hours**



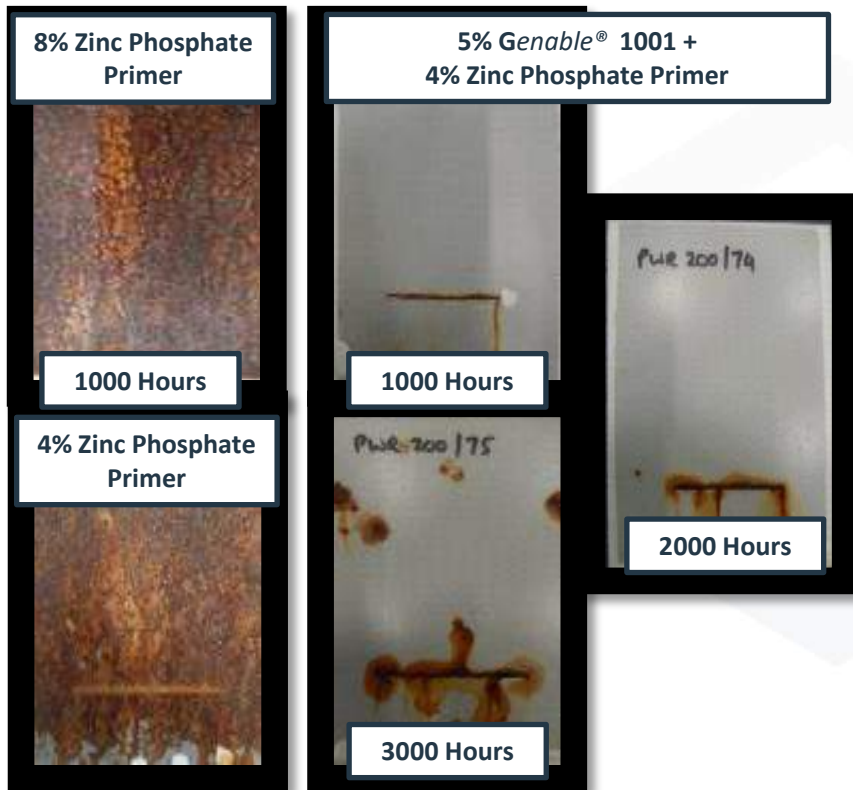
Customer Successes



Graphene Synergy Corrosion Protection



Getting the best of both active and barrier



Test panels ALL incorporating 4% wt zinc phosphate after 1000, 2000 and 3000 hours of testing to ASTM G-85-94 Prohesion Salt Spray

- Single coat spray application
- 5% **Genable**® 1001 performs best combined with 4% ZnPO₄
- Excellent extended corrosion results as a result of the synergistic performance of the Graphene in combination with 4% zinc phosphate
- Potential for optimisation of loading levels below 0.5% Graphene to meet customer performance demands



Commercial Primer Successes

Working in partnership with a leading UK based Industrial Coatings company

Target:

- Maintain the current 4 coat performance with a 3 coat system

Testing Outline:

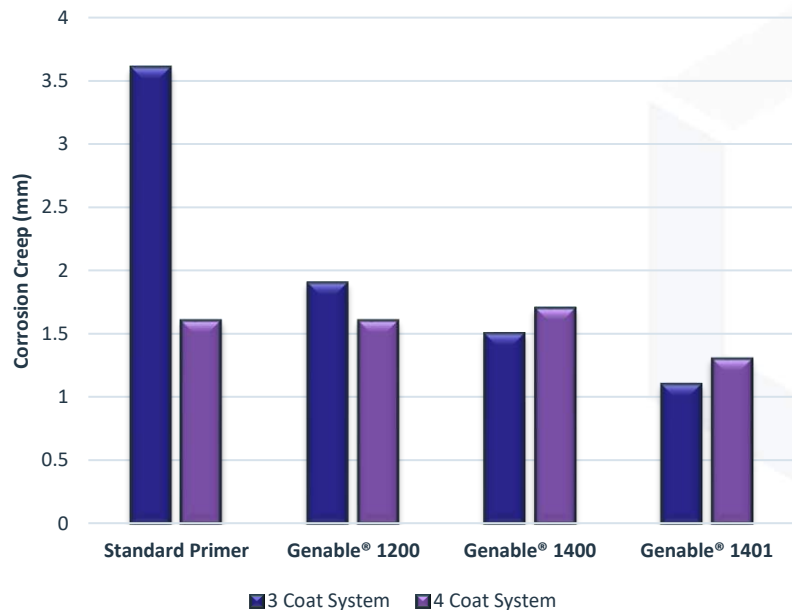
- Existing commercially available system based on Zinc Phosphate Epoxy Primer, with epoxy tie-coats and PU top
- Excellent corrosion results as a result of the synergistic performance of the Graphene in combination with 50% reduction in the zinc phosphate loading
- 5% (%w/%w) Loading levels of **Genable**® dispersion to meet customer performance demands

Graphene Synergy Corrosion Protection

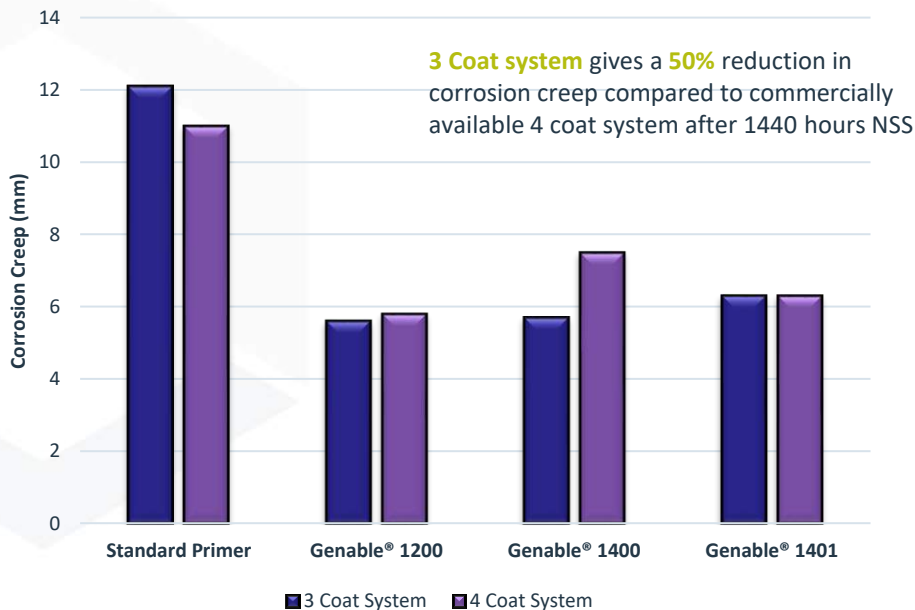
Getting the best of both active and barrier



Creep Assessment after 720 Hour Neutral Salt Spray



Creep Assessment after 1440 Hour Neutral Salt Spray

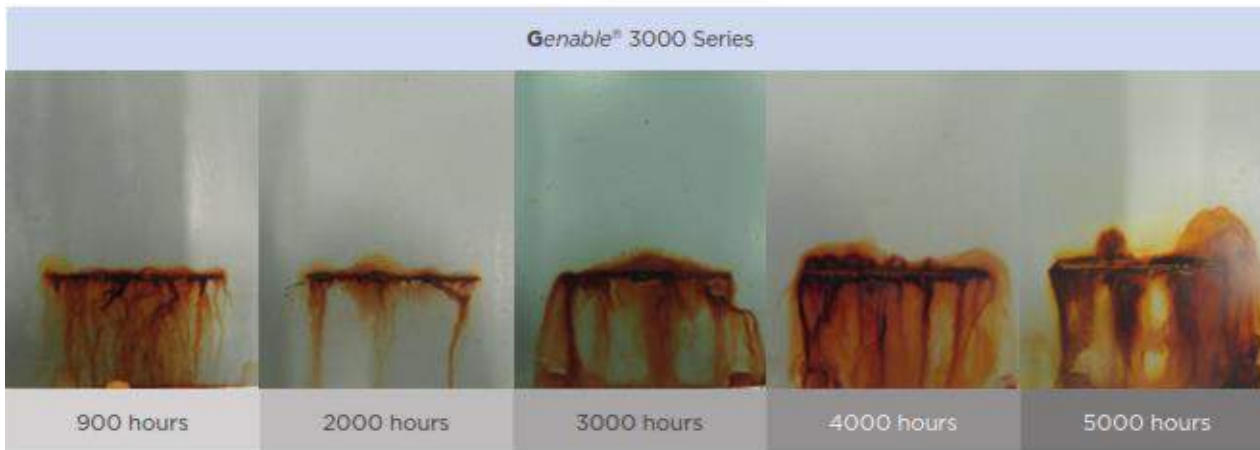


Graphene Synergy Corrosion Protection

Getting the best of both active and barrier



Synergy of **Genable**® Dispersions with non-metallic, active inhibitor pigments



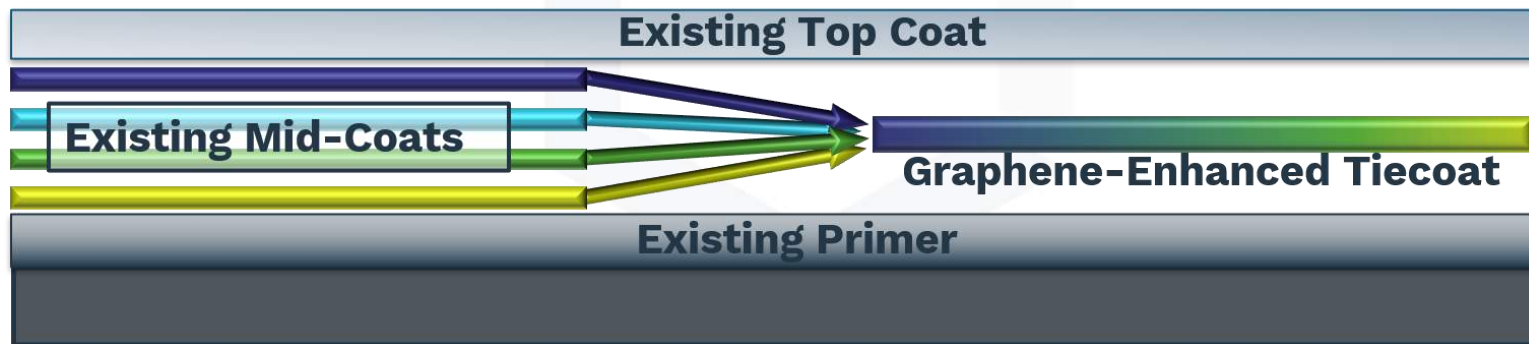
- Testing using ASTM G85 Prohesion allows for stronger correlation with natural exposure, as opposed to ASTM B117 (Continuous Salt Spray).
- **Extended durability**, with potential applications in harsh **C4**, and even **C5 environments**.
- Further work is currently underway looking at performance under Continuous Salt Spray and further significant cost optimisation.

Tie-Coat Corrosion Protection



The simple way to **Increase the Power** of your **Existing Primer**

- **Slow the rate** at which your sacrificial metal based primer is **exhausted**
- **Protect** your primer and **extend the life** of your existing coating system



Tie-Coat Corrosion Protection



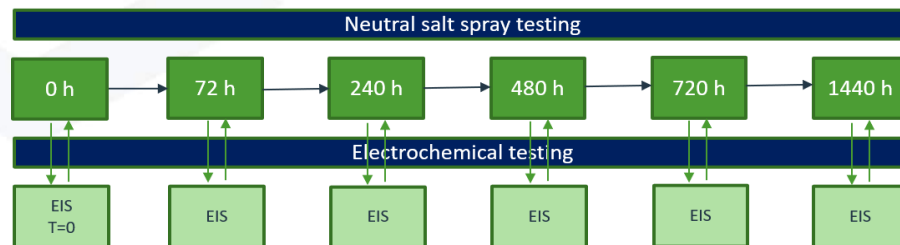
The simple way to **Increase the Power** of your **Existing Primer**

Extensive R&D study investigating the potential benefits of Graphene protecting existing commercially available zinc rich primers

Commercial Paints in Test	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

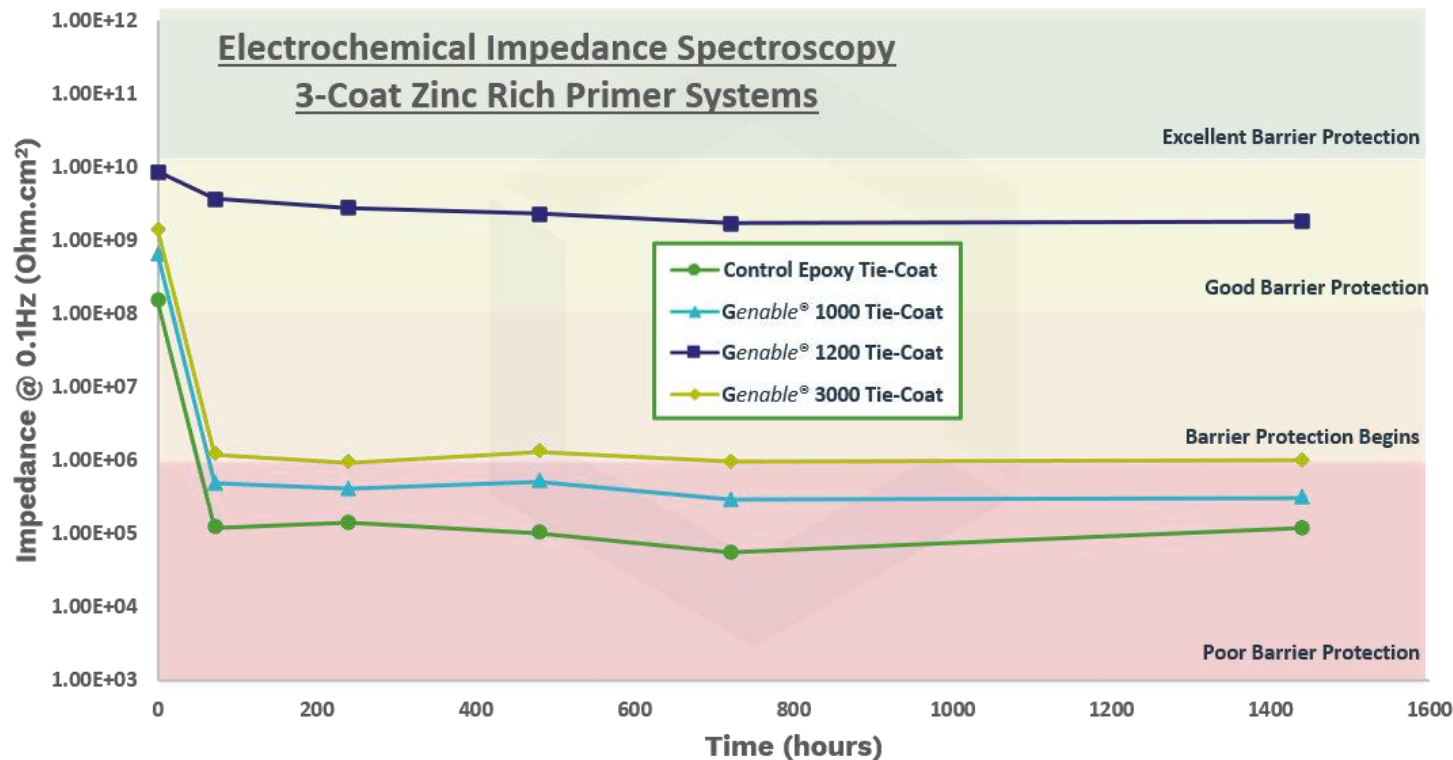
Tie Coat Systems tested	GNP (%w/w)	Active (%w/w)	PVC (%)	VOC (g/L)	Stoichiometry
Blank Epoxy Prototype	0	0	29	262	85%
Genable® 1000 Epoxy Prototype	1	0	35	262	85%
Genable® 1200 Epoxy Prototype	0.1	0	37	240	85%
Genable® 3000 Epoxy Prototype	0.5	0.9	35	253	85%

Neutral Salt Spray and EIS testing Schedule



Tie-Coat Corrosion Protection

The simple way to Increase the Power of your Existing Primer



Water-Based Corrosion Protection



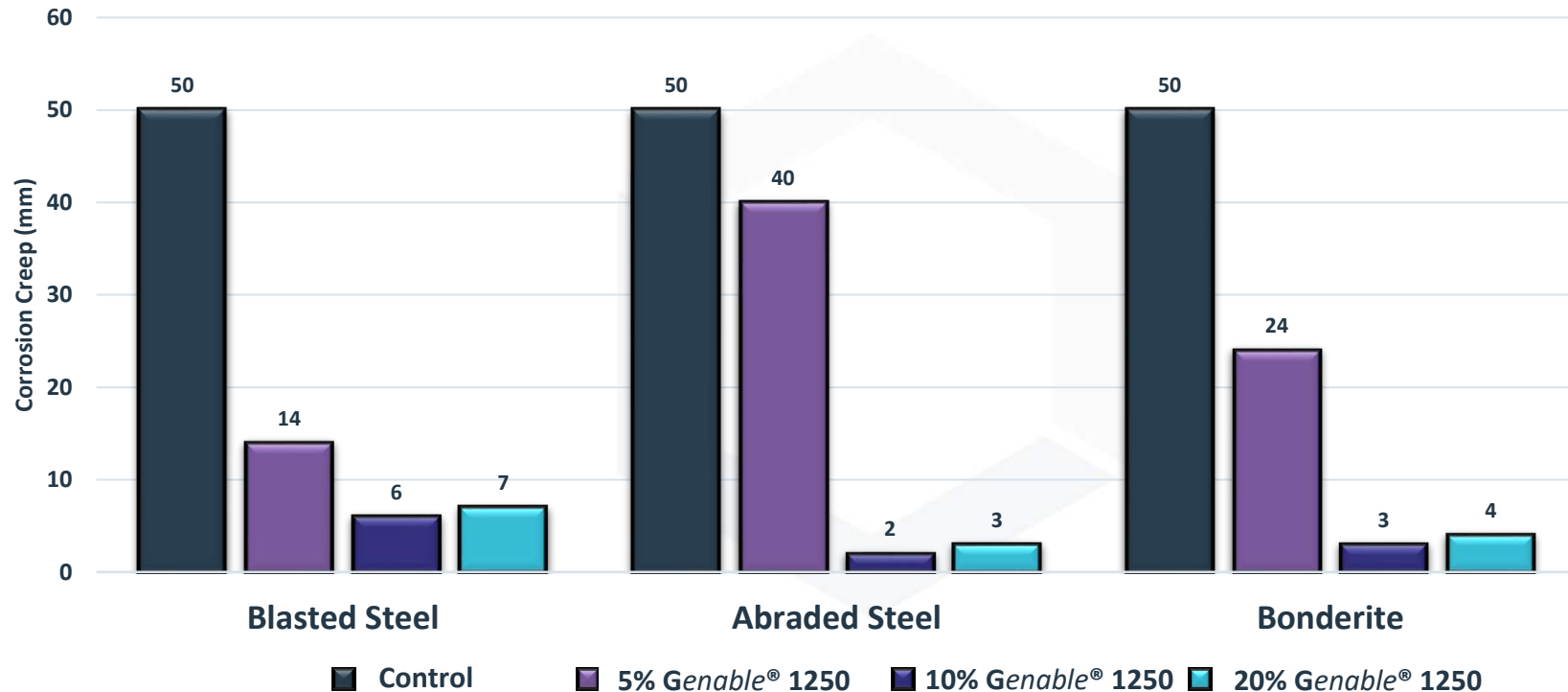
- Development of water based coatings remains a focus for industry formulators.
- Driven by the continuing tightening of regulations brought in to reduce the impact that solvent-based coatings have on both human health and the environment.
- One of the key challenges for water-based coatings is to significantly improve their anti-corrosion performance in line with solvent based systems.
- Recent AGM studies have focused on **acrylic** and **epoxy** water-based systems. Outlining the benefits of **Genable**[®] dispersion for use in water-based systems for broader industrial protective coatings.



Water Based Acrylic Development



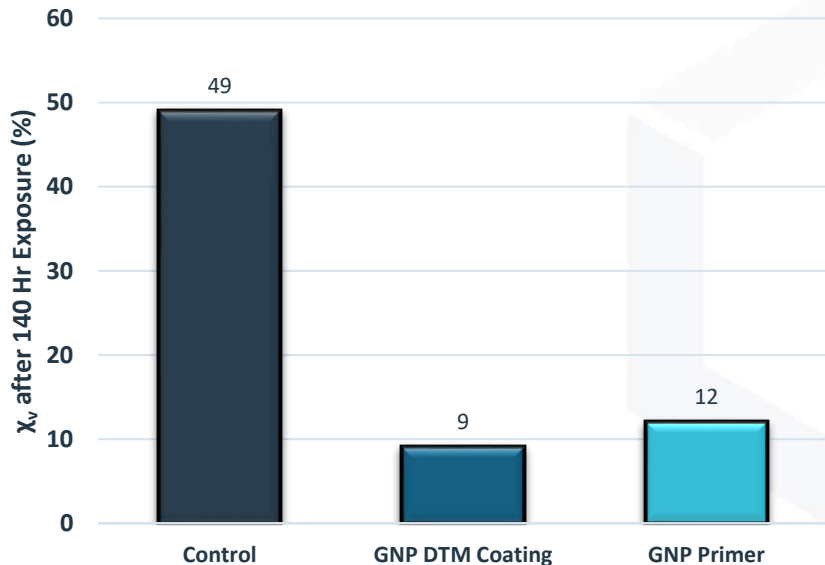
Neutral Salt Spray – 1000hours- Creep Assessment



Water Based Acrylic Development



Water Uptake from EIS Testing – after 1000 hours



Conclusions...

Corrosion Creep:

- At all loading of graphene dispersion levels, a significant reduction in the levels of corrosion creep was recorded compared to the control

EIS Water Uptake:

- The addition of 10% *Genable*® 1250 into both a direct-to-metal (DTM) and a acrylic primer resulted in a significant reduction in water uptake.
- Both Graphene based systems showed up to 40% reduction
- The reduction in water uptake suggests the graphene nanoplatelets are offering significantly improving barrier properties by increasing the tortuous path.

Water Based Acrylic Development

Salt Spray Panels – 1000 hours



Abraded Steel

Acrylic DTM Control



10% Genable® 1250 DTM



Conclusions...

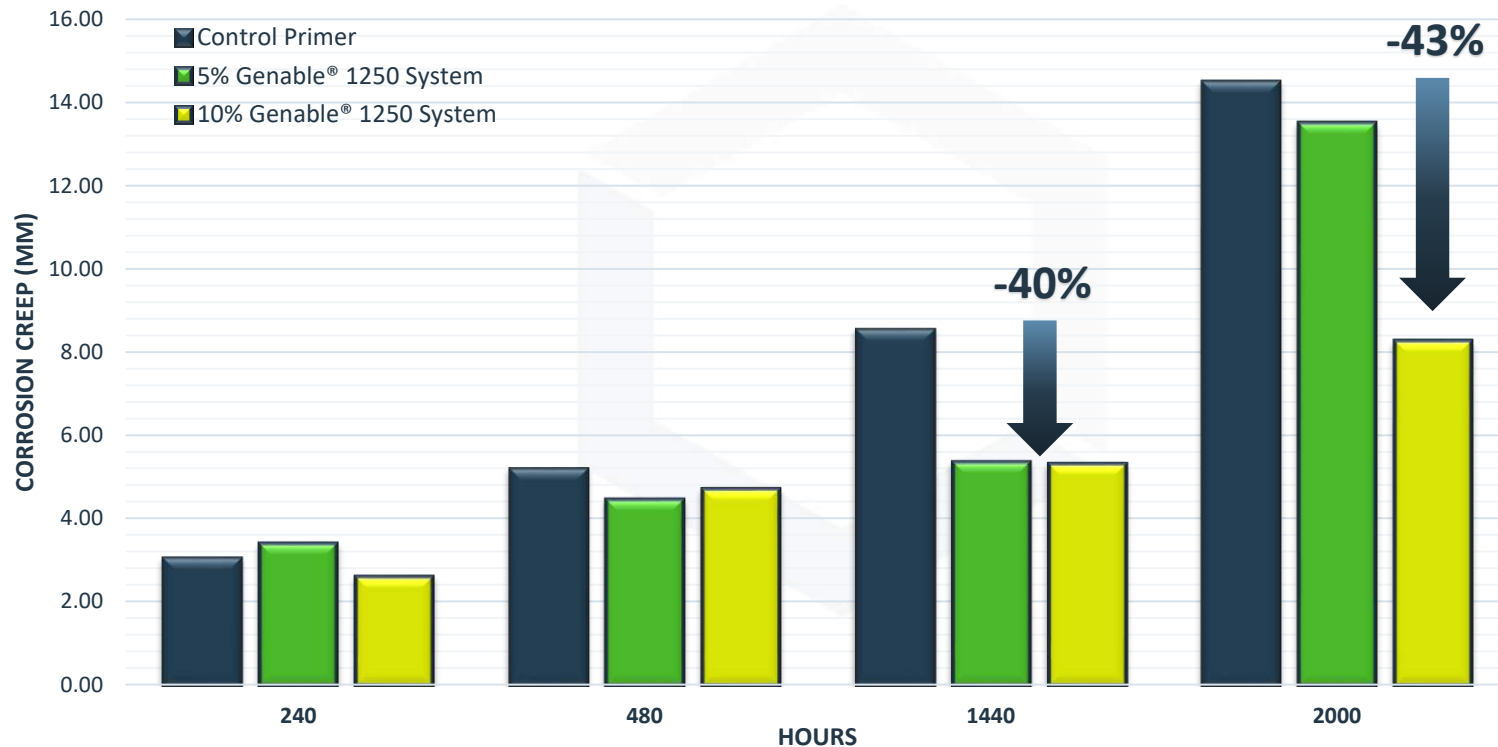
Salt Spray Testing:

- After 1000 hours, the graphene dispersion based DTM system shows significantly uplift in salt spray performance compared to the graphene free system
- The graphene based system does show some signs of cracking – it is expected that with some coating performance optimisation there would be further uplifts in performance

Water Based Epoxy Development



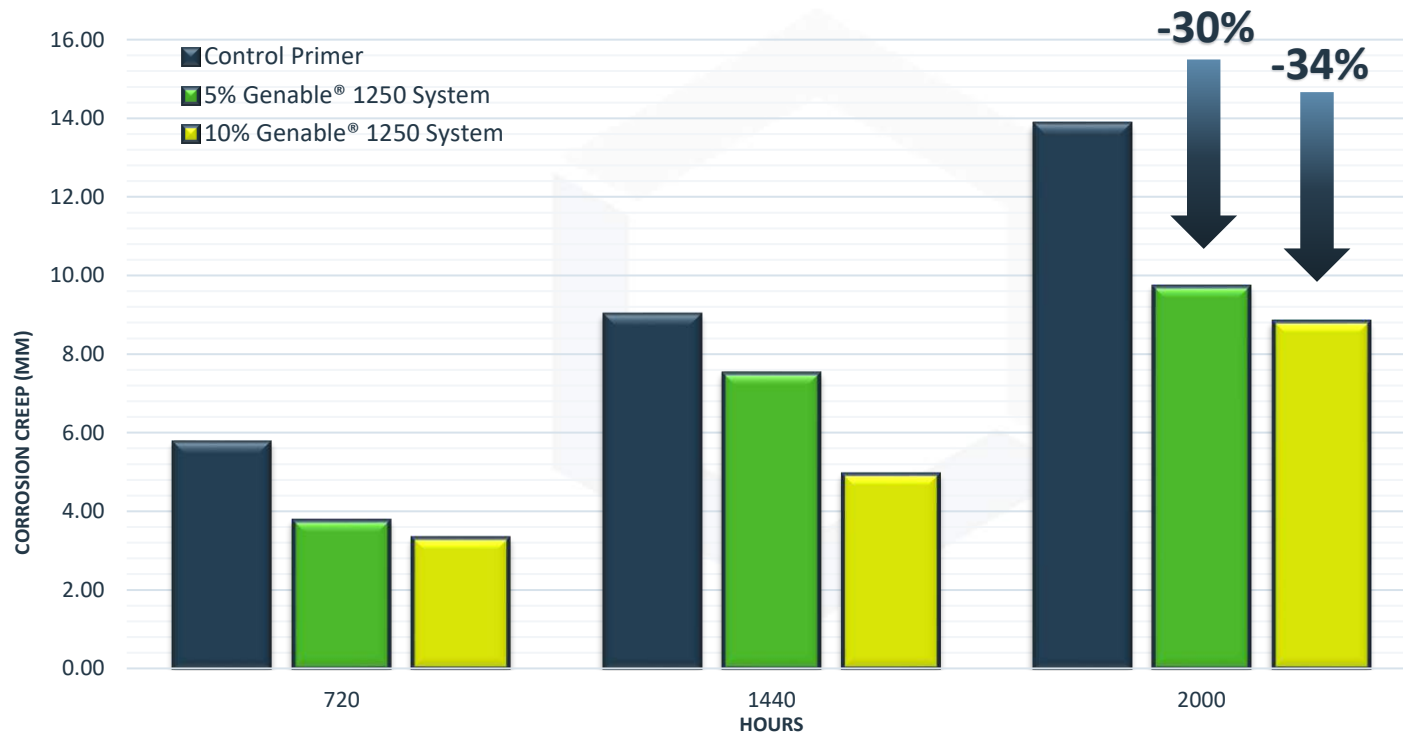
Prohesion Salt Spray – 1000hours- Creep Assessment



Water Based Epoxy Development



Neutral Salt Spray – 1000hours- Creep Assessment



Salt Spray Assessment Conclusions

Water Based Epoxy Development

Prohesion Creep Testing:

- After 1440 hours, the graphene baed system shows significantly uplift in salt spray performance with about **40% reduction** in Creep
- At 2000 hours, although the 5% **Genable**® addition was starting to fail, the 10% **Genable**® addition continues to offer excellent protection with a **43% reduction** in creep

Neutral Salt Spray

- At 2000 hours, although the 5% **Genable**® addition and the 10% **Genable**® addition continues to offer excellent protection compared to the control primer with over **30% reduction** in creep for both systems

For more detailed information the AGM Knowledge Hub at:

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