Coatings

The New Anti-Corrosion Toolbox

2021
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
- 100x Stronger than Steel
- Thinnest and Lightest Materials Known
- “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
Deploying Graphene nanoplatelets

<table>
<thead>
<tr>
<th>Property</th>
<th>Essential</th>
<th>Important</th>
<th>Interesting</th>
<th>Not needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of layers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purity – graphene content</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flake size (lateral dimensions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspect ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen content</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Metal content</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domain (grain) size</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Crystal defect</td>
<td></td>
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</tbody>
</table>

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
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
- Enhanced Pipelines coatings
- Infrastructure – chemical resistant floor coatings
- Transportation – vehicle weight reduction and anti-corrosion plus batteries
- Anti-corrosion / Chemical resistance – industrial plant
- Battery and Thermal conductivity for Electrification of Vehicles
- Coatings for Textiles
- Infrastructure – better coatings for roof, cladding, building structure
- Aerospace performance advantages for composites
- Aerospace – Aluminium corrosion protection
- Offshore harsh environment protective coatings
- Heat management potential
- Replacement of poor environmental coatings
- Environment Social Governance

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How do Graphene Nanoplatelets Work?

1g of AGM Graphene powder contains 11,200,000,000,000 individual particles.

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

10g of AGM Graphene powder would occupy a volume of 1 litre.
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 – 10m²

...0.1% Graphene Nanoplatelets – 350m²

35x the Surface Area with 1/100th of the active material
How do Graphene Nanoplatelets Work?

Comparison of Tortuous Path Length Against Mica Flake

In a standard industrial paint applied at 150µm 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 $5\mu m$...

...AGMs Graphene Nanoplatelets are approximately $3000$ times thinner
What do Genable® Dispersions do?

Water Vapour Transmission Analysis

-97.5%
-96.5%
What do Genable® Dispersions do?

Water Vapour Transmission Analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>WATER VAPOUR TRANSMISSION (G/M²/DAY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype Epoxy Primer</td>
<td>4.5</td>
</tr>
<tr>
<td>10% Genable® 1000 System</td>
<td>-30%</td>
</tr>
<tr>
<td>10% Genable® 1200 System</td>
<td>-22%</td>
</tr>
</tbody>
</table>
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

Enabling you the Opportunity to Offer Customers an Innovative Choice

Maximise the Potential of Existing Anti-Corrosion Additives in Synergy with Graphene

Simple to use, “stir-in” dispersions into New and Existing Coating Systems

Why Replace? Graphene Offers a Complimentary Technology to Existing Chemistries

Significantly Extend the Life of the Existing primer with the application of a Graphene Tie-Coat

Take Water-based Anti-Corrosion Systems to a New Level with Graphene
The Toolbox to Tackle Corrosion

- **Standalone** Corrosion Protection
- **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

Control
Graphene Based

Prohesion Salt Spray After 3000 Hours

Control
Graphene Based
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

3 Coat system gives a 50% reduction in corrosion creep compared to commercially available 4 coat system after 1440 hours NSS
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

<table>
<thead>
<tr>
<th>Commercial Paints in Test</th>
<th>Chemistry</th>
<th>Volume Solids</th>
<th>VOC</th>
<th>Recommended DFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Rich Primer (ZRP)</td>
<td>Epoxy Zinc Rich</td>
<td>59%</td>
<td>336g/l</td>
<td>50-75um</td>
</tr>
<tr>
<td>Polyurethane Topcoat (PU)</td>
<td>Aliphatic polyurethane</td>
<td>57%</td>
<td>420g/l</td>
<td>50-75um</td>
</tr>
</tbody>
</table>

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

Neutral Salt Spray and EIS testing Schedule
The simple way to **Increase the Power** of your **Existing Primer**

**Tie-Coat Corrosion Protection**

**Electrochemical Impedance Spectroscopy**

**3-Coat Zinc Rich Primer Systems**

- Excellent Barrier Protection
- Good Barrier Protection
- Barrier Protection Begins
- Poor Barrier Protection

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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

<table>
<thead>
<tr>
<th>Steel Type</th>
<th>Control</th>
<th>5% Genable® 1250</th>
<th>10% Genable® 1250</th>
<th>20% Genable® 1250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blasted Steel</td>
<td>50</td>
<td>14</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Abraded Steel</td>
<td>50</td>
<td>40</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Bonderite</td>
<td>50</td>
<td>24</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
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

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

Control Primer
5% Genable® 1250 System
10% Genable® 1250 System

CORROSION CREEP (MM)

-43%
-40%
Water Based Epoxy Development

Neutral Salt Spray – 1000 hours - Creep Assessment

- Control Primer
- 5% Genable® 1250 System
- 10% Genable® 1250 System

CORROSION CREEP (MM)

- 30%
- 34%

HOURS

720
1440
2000
Salt Spray Assessment Conclusions

Water Based Epoxy Development

Prohesion Creep Testing:

- After 1440 hours, the graphene based 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:*  