WCX Digital Summit

Graphene for Automotive
Lighter, Stronger, Better
DR ADRIAN POTTST

Chief Executive Officer

Materials Scientist by training

Joined AGM in January 2015, CEO from August 2018

30+ years in various senior roles in carbon fibre composites industry

Experienced in strategy development, business turn-arounds and integrating new innovation
Graphene – Remarkable performance. How to realize it?

**Single layer Graphene**

- **Mechanical**
  - 100X stronger than steel
  - Stiffer than diamond

- **Transparent**
  - Circa. 98% optical transmission

- **Impermeable**
  - Vacuum tight to helium gas

- **Electrical**
  - 60% greater conductivity than copper

- **Thermal**
  - 5X conductivity of Al

- **Lubricating**
  - Very low surface shear

**Graphene nanoplatelets**

- **It is a matter of matching the right material at a certain price point to specific application and performance objectives**

- **The Graphene Council Graphene Commercialization Report 2020**

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Paper # (if applicable)
Graphene – Remarkable performance….. into reality

• Making graphene work - “If you can add graphene to it correctly, you can make great use of the materials advantages”

• The keys.....

• Application Technology – clear understanding of end-use need and how to achieve it
  • Deep engagement with end customer
  • Understand objectives and needs
  • Customised solution – End-use specific

• “How-To” data enables easy use of graphene
  • Impressive data to support claims
  • How-To knowledge to assist the customer
  • Regulatory leadership for use of nano-materials

• UNLOCKING USE OF GRAPHENE for:-
  • Coatings
  • Composites
  • Printing
  • Thermal Adhesives
Lighter & Tougher  Graphene in Composites
Lighter & Better  Graphene in Thermal applications
Better & Longer Life  Graphene in Coatings
Lighter & Tougher - Graphene in composites - Status

- **Scope:** Improved mechanical performance and further weight reduction
- **Process route:** Graphene dispersions into Carbon Fiber Prepreg materials
- **Potential for further lightweighting through careful materials engineering with graphene in matrix resin**
- **Early demonstrators – parts in graphene enhanced prepreg such as W Motors**

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**MTC9810**
Graphene Enhanced Epoxy Component Prepreg

**Introduction**
MTC9810 is a revolutionary graphene enhanced, honeycomb bondable epoxy resin system designed to produce a durable cost effective component with an excellent surface finish along with enhanced resin toughness. It can be supplied on a variety of fabrics and in UD format to meet your cost and manufacturing requirements.

**Typical applications:** High performance, motorsport, sporting goods

**Commercially available graphene prepregs with GNP’s for high fracture toughness / outstanding surface finish**
Lighter & Tougher - Graphene in composites - Status

- **Scope:** Cryogenic pressure vessels for potential use in multiple NASA spaceflight missions
- **Process route:** Graphene dispersions into Carbon Fiber winding system
- **AGM's GNP's dispersed into 2 resin systems**
- **Matrix mechanical enhancement plus barrier diffusion performance**
- **AGM's GNP's enabled tanks liquid oxygen loading test at -300ºF pressurized to 600 psi.**
- **Eliminated nearly all microfractures in resin samples after exposure to cryogenic cycling**
- **Commercial use – Tanks including cryo tanks for space with Infinite Composites**

Careful selection of correct graphene in correct format and dispersed in the appropriate materials enable longevity of flight critical parts. Potential read across to vehicle pressure vessels for hydrogen power
Lighter & Tougher - Graphene in composites - Status

- **Scope:** Work with major automotive Tier 1
- “We can see positive directional improvements in key mechanical properties of composites systems. Encouragingly, other mechanicals investigated did not show significant change as compared to baseline numbers.”

- **Areas of substantial performance gain include:**
  - ✓ Tensile Strength and Modulus improvements
  - ✓ Flexural Strength and Modulus improvements
  - ✓ Impact performance improvements

- **Alignment to trends in vehicle technology:**
- Potential to design out mass for light weighting through increased mechanical performance with graphene in a range of composites process routes
  - Chassis and body panels with range of composites process solutions
- Pressure vessel potential benefits for mass transit, particularly in Asia
Lighter & Tougher - Graphene in composites – Further Development

- Printed large platelet graphene for composites
- Formulated Structural Ink™ Graphene Ink printed onto composite materials
- Fracture toughness improvements in continuous fiber composites:
  - Matrix resin alone + 170%
  - Composite + 130% and printing only where needed

- Alignment to trend in vehicle technology:
  - Read across to consider printed conductive networks of printed materials.
  - Offset weight of wiring in a vehicle for eg LED’s
Lighter & Tougher  Graphene in Composites
Lighter & Better  Graphene in Thermal applications
Better & Longer Life  Graphene in Coatings
Lighter and Better - Graphene for thermal applications - Status

- Low Density / High thermal conductivity materials
- Aerospace heat spreader applications

- High conductivity low density adhesives
- Currently in 2 pack thermal adhesive format
- Meter and mix capable for volume use

- Performance attributes
  - Up to 6 W/m-K
  - Low density
  - Adhesive performance
  - Low outgassing

- AGM Genable 4400, 4300 and TP300, TP400 products commercially available
Thermal - Graphene for thermal – possibilities for graphene

- Growth of EVs is projected to rise steadily to 2030 and with that the use of Thermal Interface Materials (TIM)
- U.S. DoE’s National Renewable Energy Laboratory note 3 reasons for thermal management for batteries:
  - Operation in optimal temp range of 15-35°C.
  - Reduce uneven temperature distribution in cells < 3-4 °C
  - To eliminate potential hazards related to thermal runaway

- TIM use within battery packs - cooling plate-module, module-cell, cell-cell/heat spreaders
- Mechanical and thermal connection usually done by use of thermally conductive adhesives and thermal interface materials
- Graphene good potential with correct dispersion and particle formatting
Thermal - Graphene for thermal – possibilities for graphene

- Current thermal paste performance range of 0.5 - 12 W/m-K
- AGM product at ~6 W/m-K
- Potential future developments as demonstrated in literature may improve the Thermal Conductivity Efficiency
- Raising performance to 30-40 W/m-K via:
  - Controlled alignment may be used to improve through plane conductivity
  - Development of segregated networks
  - Use of carbon and carbon/metal hybrids

- Plenty of scope for smart materials engineering and potential hybridising to achieve high thermal efficiency
- Need for all the tools to be in place – materials, dispersion methods and chemistries, application know how
- Graphene has good potential to contribute in this space
Section

Lighter & Tougher  Graphene in Composites
Lighter & Better  Graphene in Thermal applications
Better & Longer life  Graphene in Coatings
Better - Graphene in coatings. Status

- Graphene works incredibly well for anti-corrosion / barrier applications / chemical resistance paint and coatings applications
- AGM at forefront of anti-corrosion effort and development of:
  - Dispersions to suit formulating - SB and WB coatings in a range of chemistries
  - Formulated additive products for a range of barrier enhanced coatings. Low dosing levels
  - Focused on primer products – high levels of effectiveness
  - Replacement of environmentally challenging actives in primers
  - Application expertise to enable engagement end to end

![Control vs Graphene Based](image)

**Typical – automotive sprayable primer system results - 3000hrs test in salt spray. 0.1% graphene add**

![Comparison Table](image)

**3000hrs ASTM G85-94 Prohesion test. 0.5% graphene add**
Better - Graphene in water-based coatings - Status

- Graphene based dispersion additives solution for water-based coatings
- AGM has a range of prototype water based coatings, enhanced with graphene nanoplatelets
- Reductions in corrosion creep with increasing loading of graphene.
- Significant reductions in water uptake which point to increased barrier properties.
- Minimal changes to coating gloss
- Resultant grey coating lighter than the commercial grey primer - room to colour match

Neutral Salt Spray after 1000 hours – Creep Assessments

- The addition of 0.05% graphene resulted in a significant reduction in water uptake.
- Both systems showed a 75-80% reduction
- The reduction in water uptake suggests the graphene nanoplatelets are improving barrier properties by increasing the tortuous path.
Automotive Interiors Coatings – possibilities for graphene

- Interiors are a darker color so benefit potential for graphene
- Intensive use of vehicles forecast to increase
- Materials tend to be coated
- Risk of deterioration with time
  - Use and wear
  - Sun cream
  - Bug spray
  - Sweat
  - Drinks
  - Staining / colour change / cracking / deterioration
  - Mar resistance
  - Touch screen capability
  - Anti-scratch
- Need for barrier performance to improve life and performance of WB PU interior coatings

Graphene has plenty to offer in this space
- Diffusion control
- Barrier
- Deterioration from Moisture / UV
Auto trends in coatings and potential graphene fit

**Importance of Water-based chemistries - a key focus for auto coatings formulators**... Dispersing graphene for WB coatings crucial for success

Auto coatings manufacturers are dedicating serious R&D efforts in formulating cutting edge WB coatings.... know-how with graphene additives to enable participation

Increasingly strict environmental regulations for VOC emissions has lead to WB technologies.....graphene works well in WB liquid anti-corrosion primers. Strong lead from Chinese market in enforcement

**Low VOC Powder coating technology for primers important for USA market**.....possibilities for graphene technology in this space

Evolution of smart coatings to meet the need of surface durability plus other functionalities like self healing, self sensing, sound proofing and vibration damping ....graphene potential to fit with these needs individually or in tandem

Shift in future trend away from ownership to car-share / ride share. Intensity of use needs robust coatings. Graphene has great potential

![Car-sharing - the “car2go” model](image1)

![Ride-hailing - the “Uber” model](image2)

**Figure 2. Automotive coating layers, their thicknesses and purposes for an exterior surface.**

Coatings 2016, 6, 24
Summary – Graphene for Automotive

• Lighter & Tougher
  • Potential of Graphene dispersions for structural enhancement of composites / lightweighting
  • Process method agnostic – Graphene works in a range of process methodologies

• Lighter
  • Potential of Graphene Inks for selective applications
  • Potential for thermal applications for graphene especially with growth in EV market
  • Scope for TIM’s and thermal adhesives

• Better
  • Proven coatings technology for barrier corrosion, robustness
  • Plenty of opportunity in the coatings space for novel materials technology
  • Evolution of mixed substrate materials. Graphene works on steel and aluminum.
  • Battery coatings a prime area for development for thermal, dielectric, impact, corrosion
Send questions/comments to:-

Thank you

- Adrian Potts
- Applied Graphene Materials plc
- The Wilton Centre, Redcar, TS0 4RF, United Kingdom
- Employee contact Offices in USA in Louisville and Tulsa
- +1 (918) 344 8564
- adrian.potts@appliedgraphenematerials.com