Enhancing Composite Materials with Functionalized Graphene & CNTs

Haydale Technologies Thailand (HTT)

November 9, 2016

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THE FUTURE IS... POSSIBLE

Brief Overview of HTT

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HAYDALE TECHNOLOGIES (THAILAND), is a subsidiary of Haydale Graphene Industries plc., UK., located in Thailand Science Park, Pathum Thani.

The company (HTT) is the Thailand top 10 innovation business 2012, that has developed, in conjunction with the Thailand National Science & Technology Development Agency (NSTDA), ***a one-stage exfoliation/dispersion process to create a range of graphene-enhanced transparent conductive inks*** for inkjet and other printing platforms. They have also now developed ***a graphene enhanced PLA (Poly-Lactic Acid) resin*** (commonly used in medical devices and 3D printing) that shows improved mechanical and barrier performance without sacrificing transparency.

HTT's mission is to be a solutions provider of Functionalised Graphene composite and Printed electronics applications for ASIA MARKET.

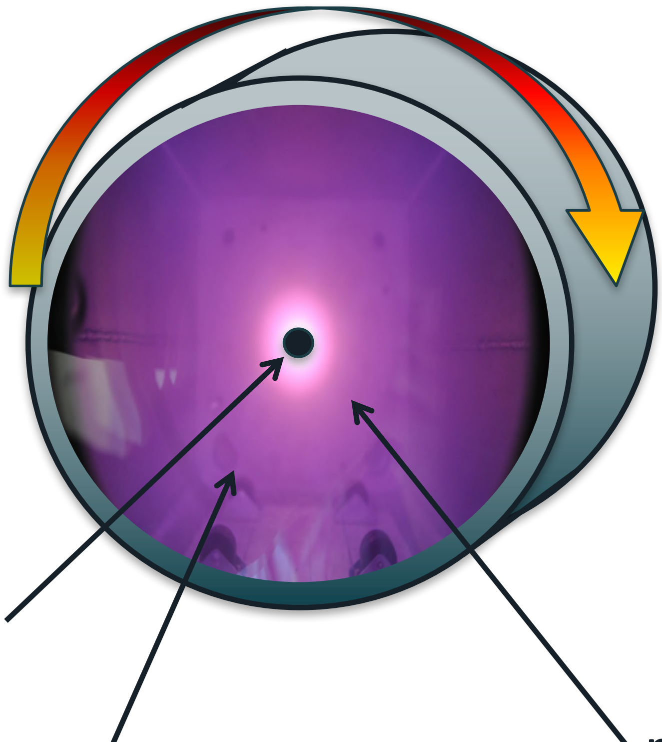
Thailand Science Park

HTT Facilities

HTT's new 340 Sq.m. research facilities have focused on 4 main solutions.

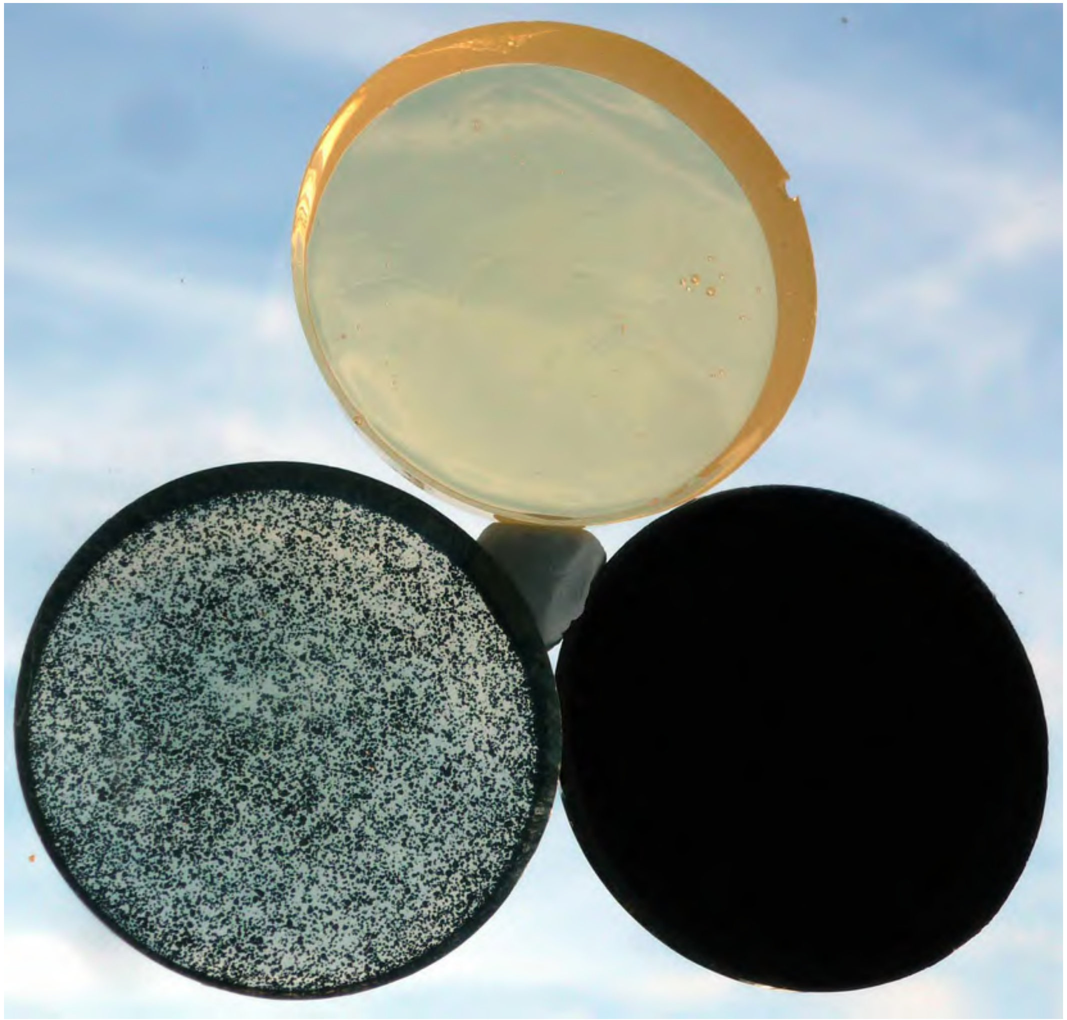
- **Functionalized Graphene Solutions**
  - Low-temperature plasma reactor unit
  - Initial Capacity 0.8 to 1 ton/Yr.
  - Future expansion to 20 Tons/Yr.
  - Full Q.C. equipment
- **Conductive Ink Solutions**
  - Conductive Ink Production unit
  - Exfoliated Graphene production unit
  - Capacity from 500Kg./Yr. to 5 T./Yr.
- **Composite Solutions**
  - Masterbatch unit
  - PLA Filament production unit
- **Printed Electronics Solutions**
  - All Printed electronics platforms; inkjet, R2R and Screen printing.
  - Various expertise; Electrical Engineers, Biotechnologies, Materials Science.

Haydale HDPlas Functionalisation



1. Low pressure gas plasma generated from controlled gas and vapour mixtures
2. Ionized gases (plasma) interact with the CNT/GNP surface, attaching “free radicals”
3. Plasma attacks and removes impurities

Dispersion Improvements



Epoxy (no filler)

0.5 wt% **NON** Functionalised CNTs in epoxy resin

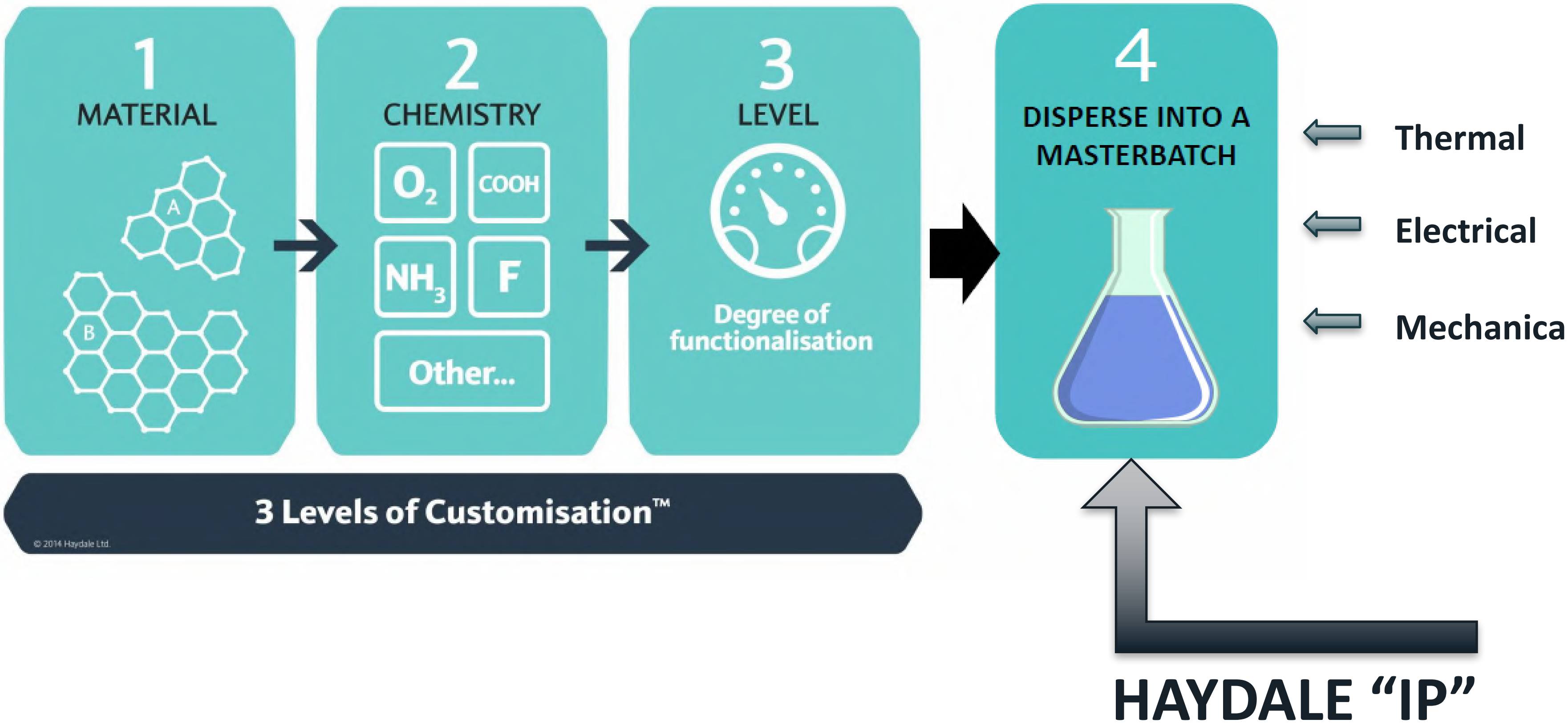
0.5 wt% HDPlas™ Functionalised CNTs in epoxy resin

Dispersion Improvements

HDPlas™
MWCNT
in Oil

As supplied
MWCNT
in Oil

The Haydale Approach



Graphene Enhanced Polymers Dependent Properties

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Adding graphene to polymer resins can radically change the performance of both the polymer and polymer composite material in the following 4 areas.

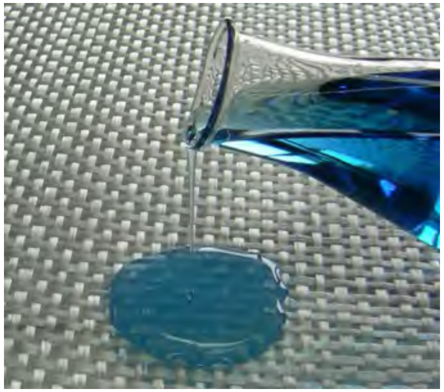
Mechanical Performance - **e.g. Compression after Impact. Strength and Stiffness, Shear etc…**

Electrical Performance - **e.g. Lightning Strike, EMI/EMC, Anti Static etc…**

Thermal Performance - **e.g. Thermal Conductivity**

Physical Performance - **e.g. Permeation Resistance, Shrinkage**

Thermosets

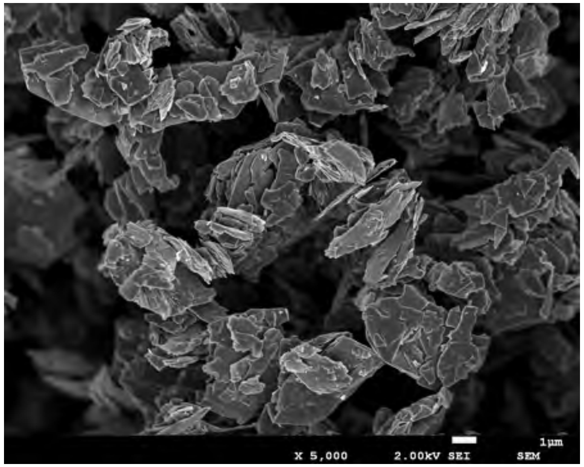


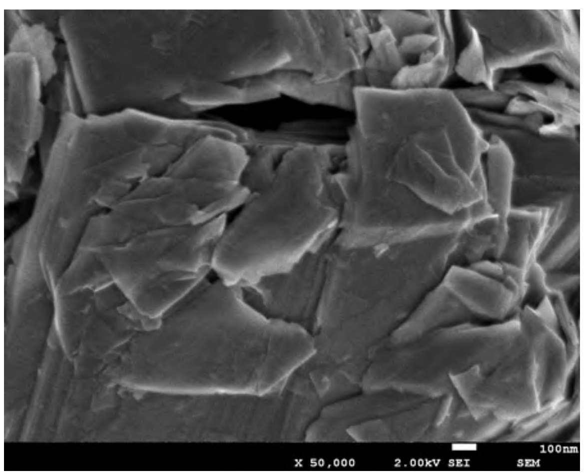
Thermosets

Polyester, Epoxy, Polyurethanes

- **Liquid at Room Temperature**
- **Chemically Cured**

Thermosets: Mechanical Strength

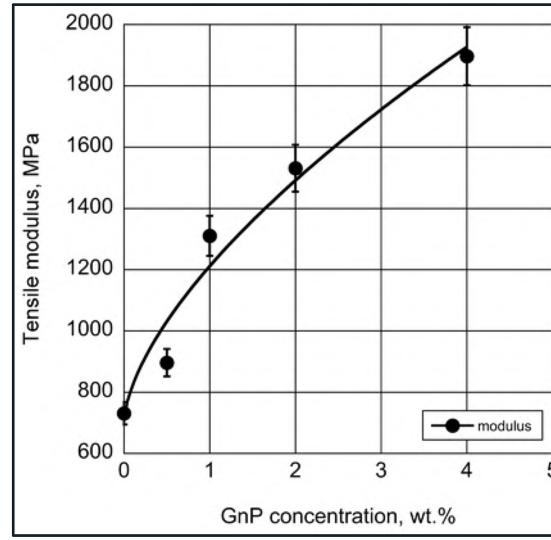


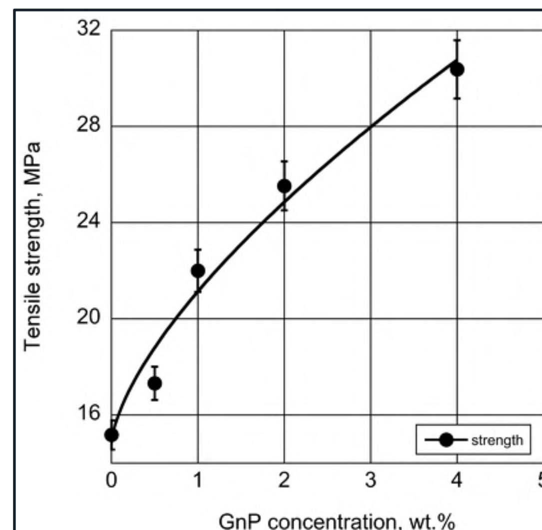


Aerospace Corp

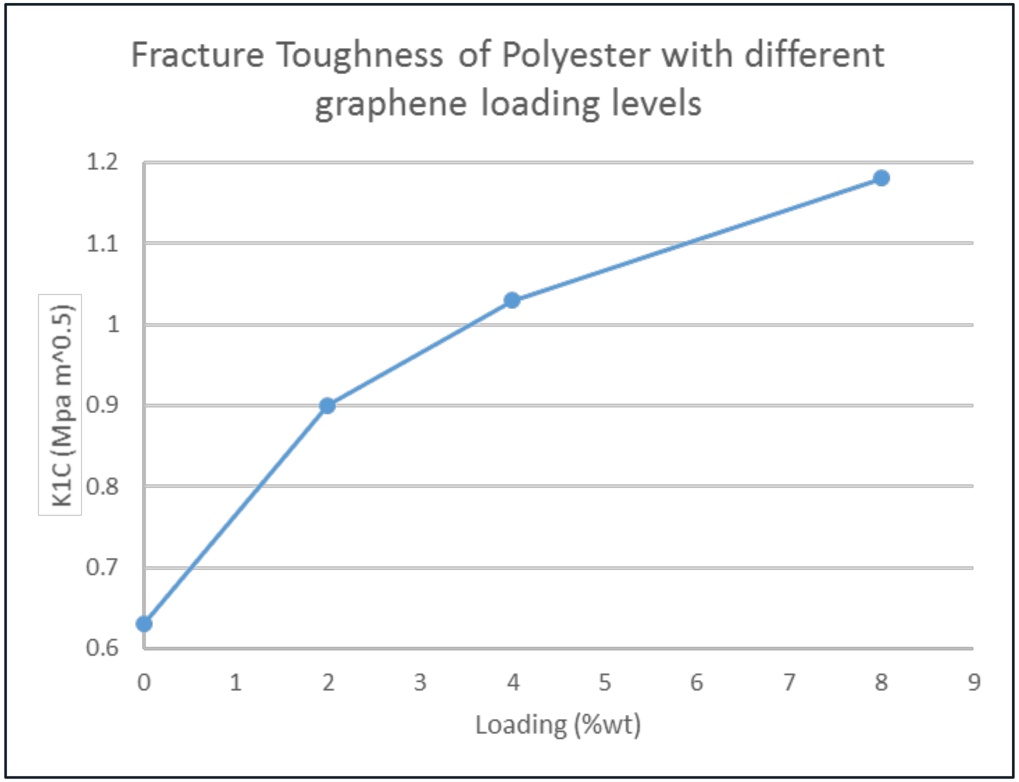
- Accepted for publication in a peer reviewed journal in April 2014
- Haydale GNP cited
- Significant strength improvements in toughened epoxy composites
- The addition of increasing amounts of GNP resulted in significant strength increases and toughness improvements over that of similarly cured, unreinforced material.
- Marketing opportunity!

Reported in the Journal of Applied Polymer Science 10.1002/APP.40802





Mechanical Performance: Fracture Toughness



- Improved fracture toughness
- Improved impact resistance
- Improved compression after impact

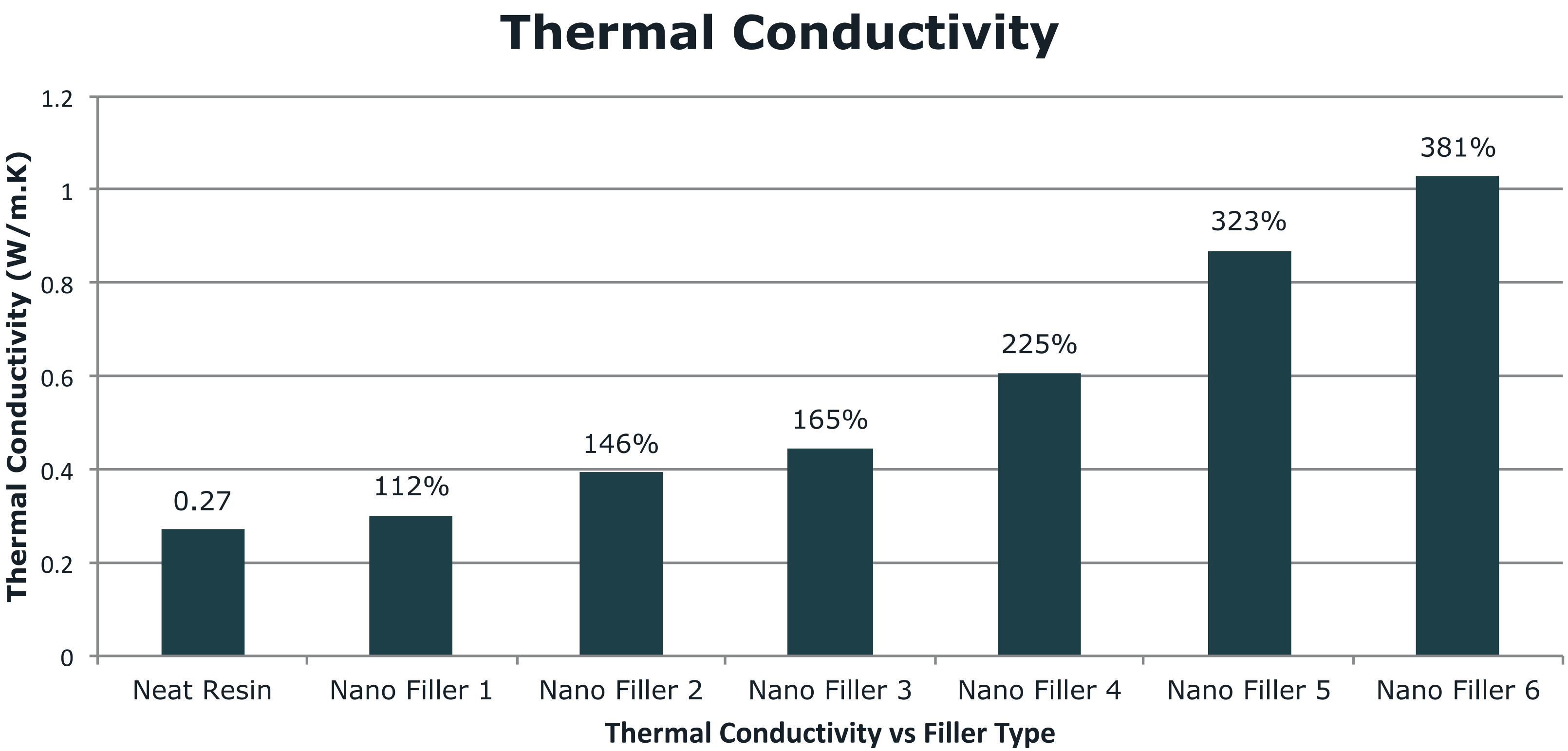
Infrastructure
GRP Pipes, Construction Products

Aerospace and Defence
(Ailerons, Leading Edges, Cowlings etc)

Automotive
(F1, Rally, bodywork)

Sporting Goods
(Rackets, hockey stocks, helmets, bike frames)

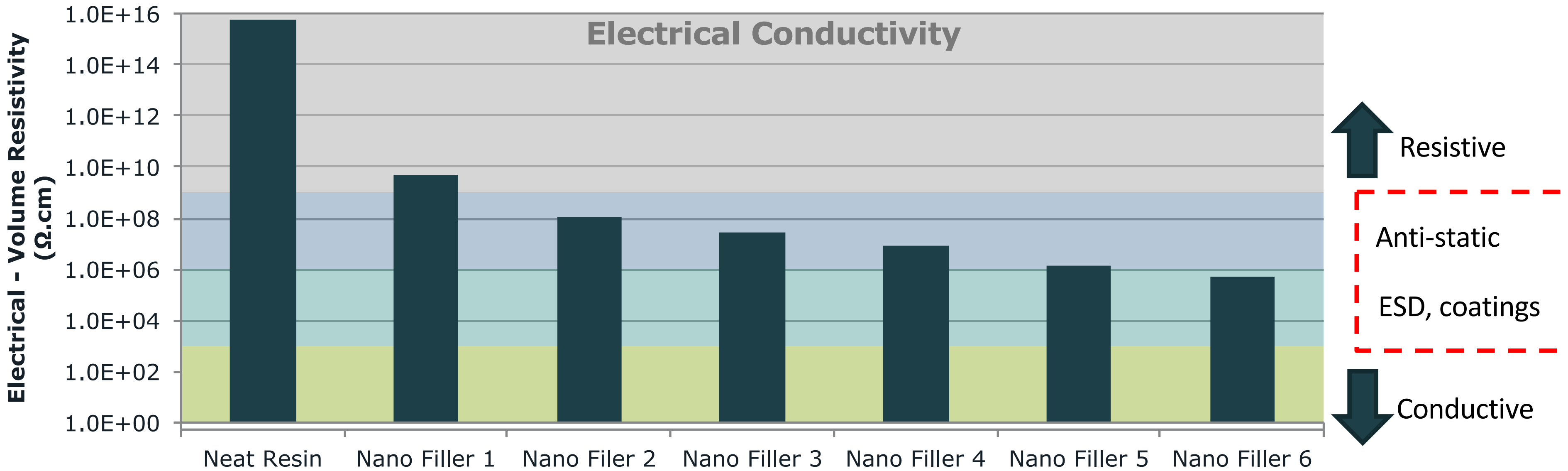
Thermosets: Thermal Conductivity



- Faster moulding times
- Reduce exotherm and microcracking
- Thick section mouldings

Wind turbine blades
Pressure vessels
Pipes
Mould tools

Thermosets: Electrical Conductivity



- Aircraft lightning strike prevention
- Electronic cases and enclosures
- Conduits and cables
- Antennas
- Reflectors

Aerospace
Telecoms and Power Utilities
Medical
Defence

Thermosets: Applications

Thermally Conductive
Mould Tools

Graphene Enhanced Carbon
Composite Panels

High Impact Resistant Graphene
Enhanced Composite Pipes

Graphene Enhanced Carbon Fibre
Wings for Unmanned Aircraft

Thermoplastics

Why Add Graphene and Other Nano Materials?

Increase Strength, Stiffness and Toughness

Increase Electrical Conductivity
-EMI/EMC Shielding and Anti-static

Increase Thermal Conductivity

Thermoplastics: Mechanical Strength

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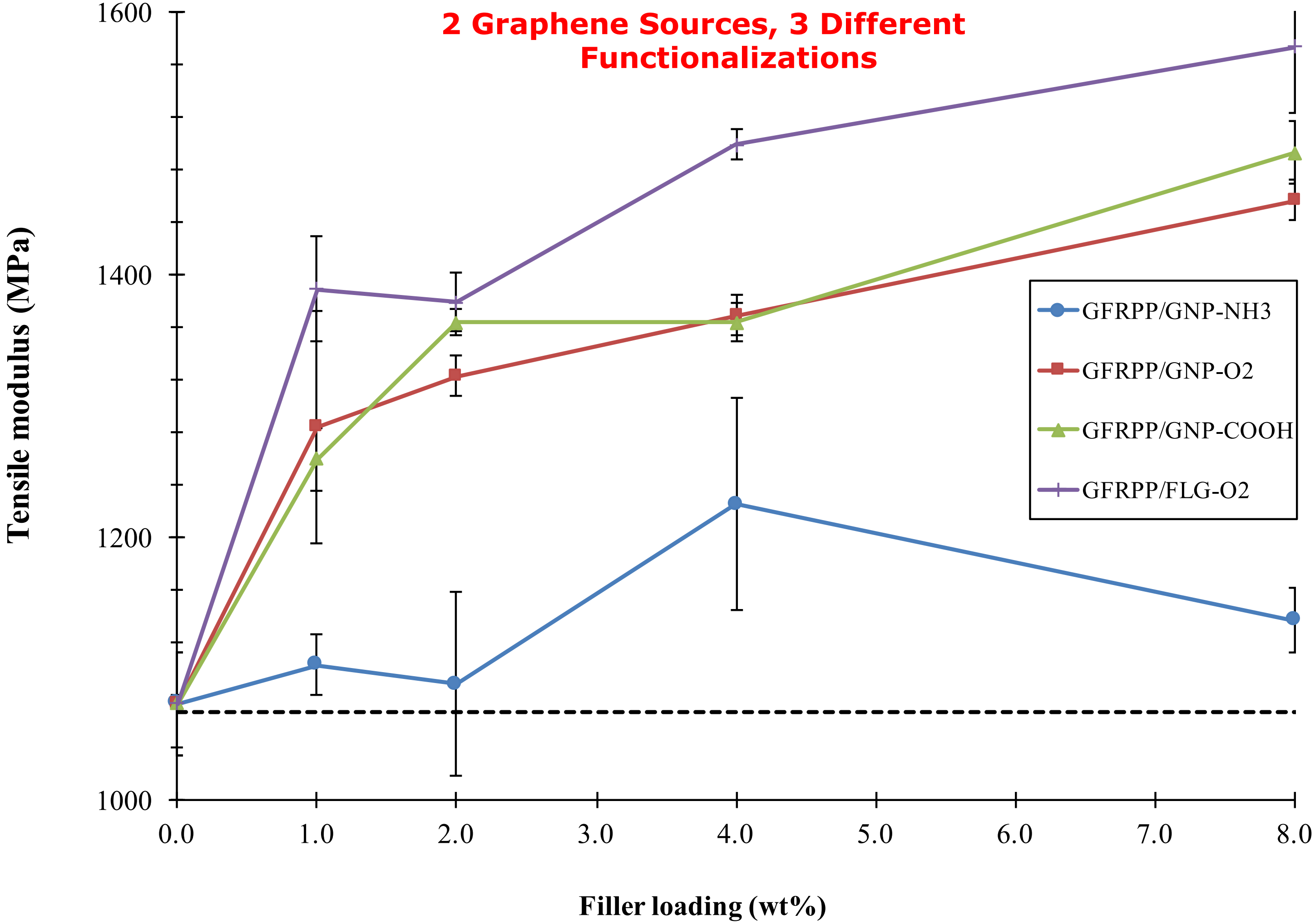
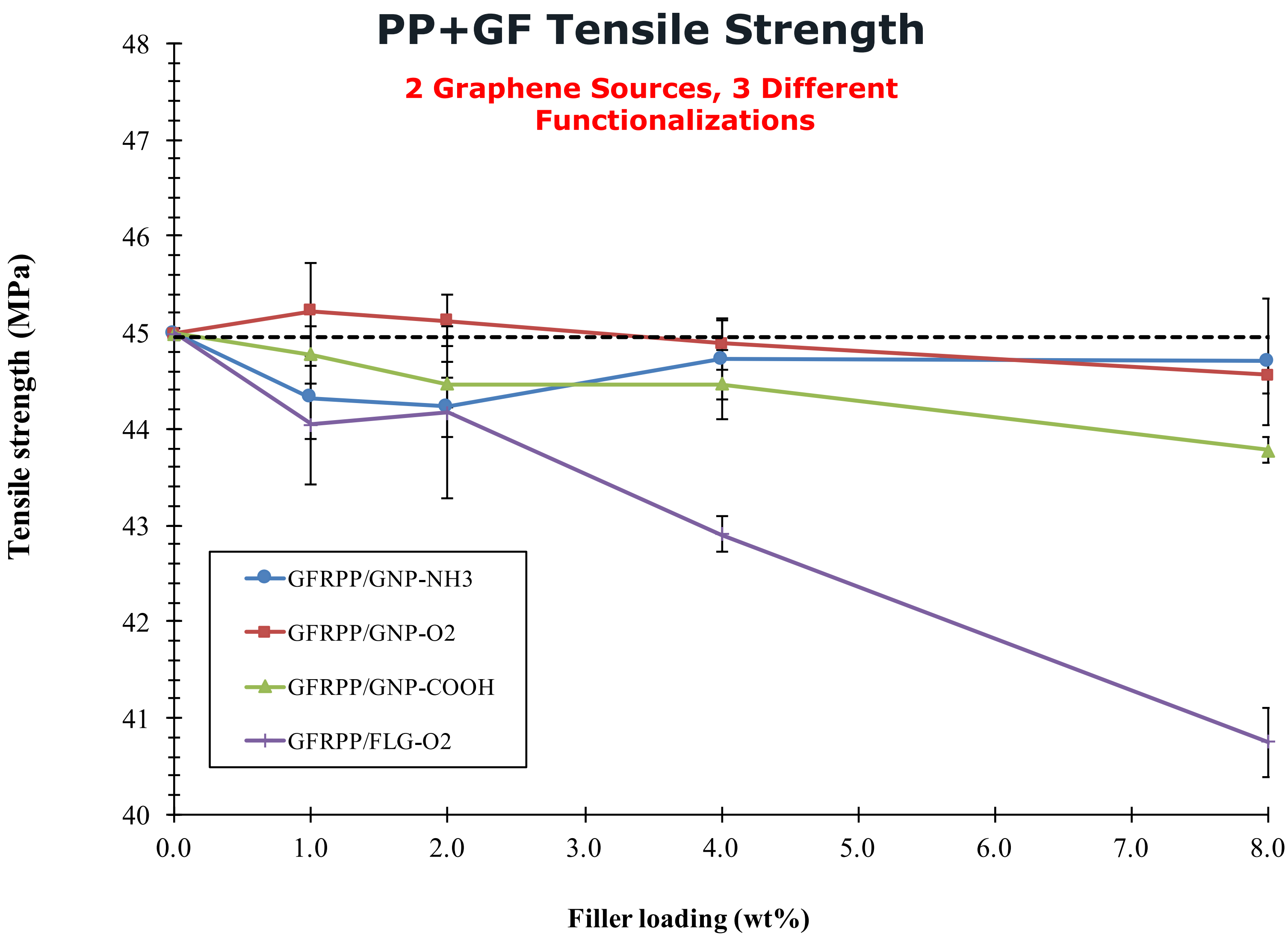
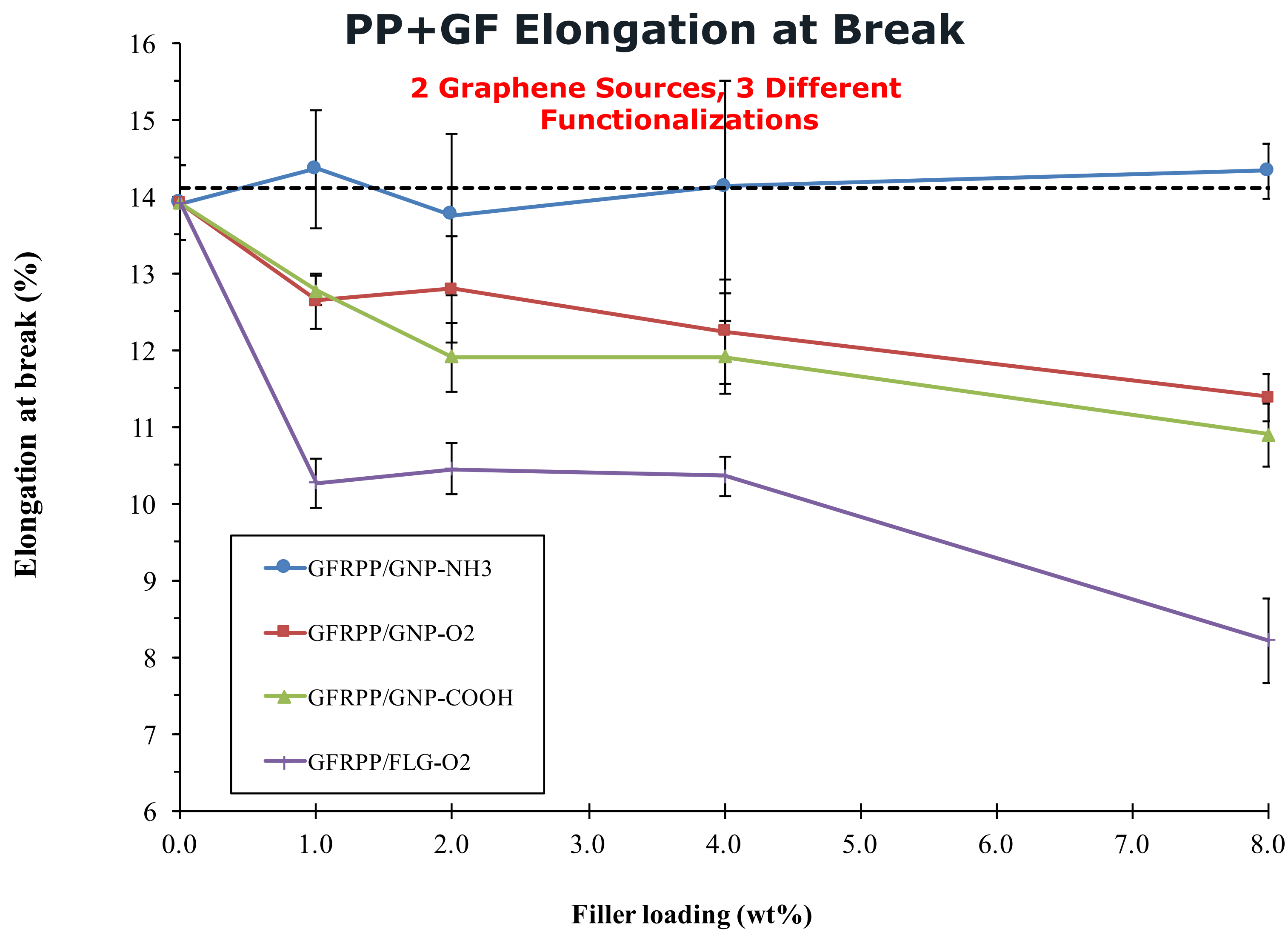
PP+GF Tensile Modulus



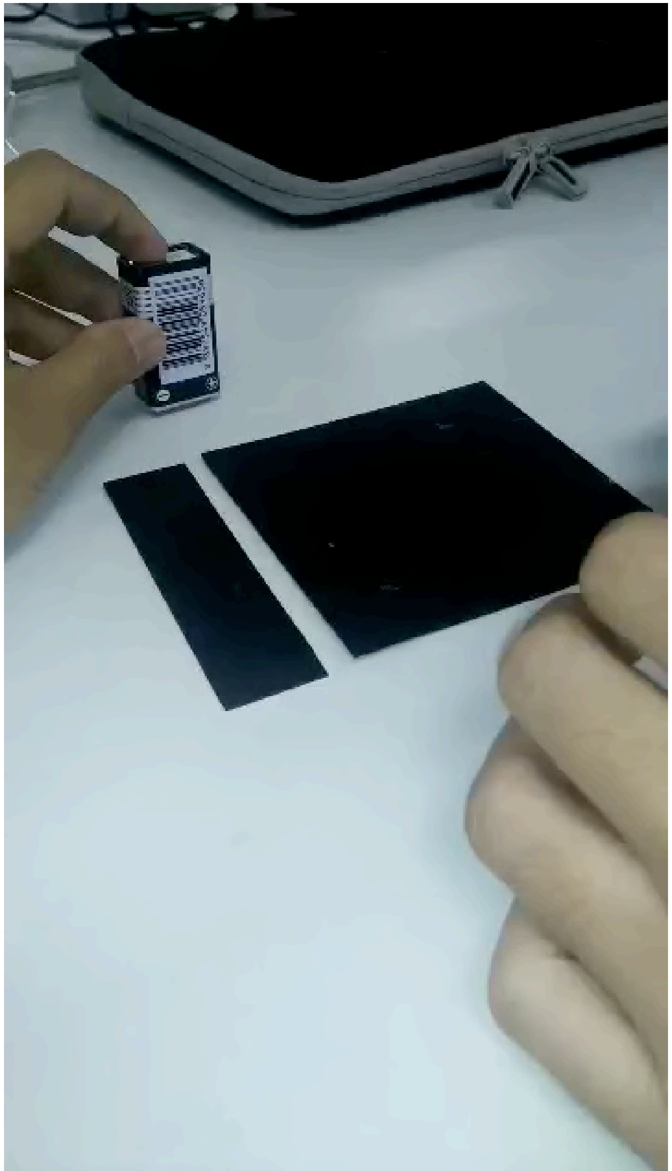
Thermoplastics: Mechanical Strength



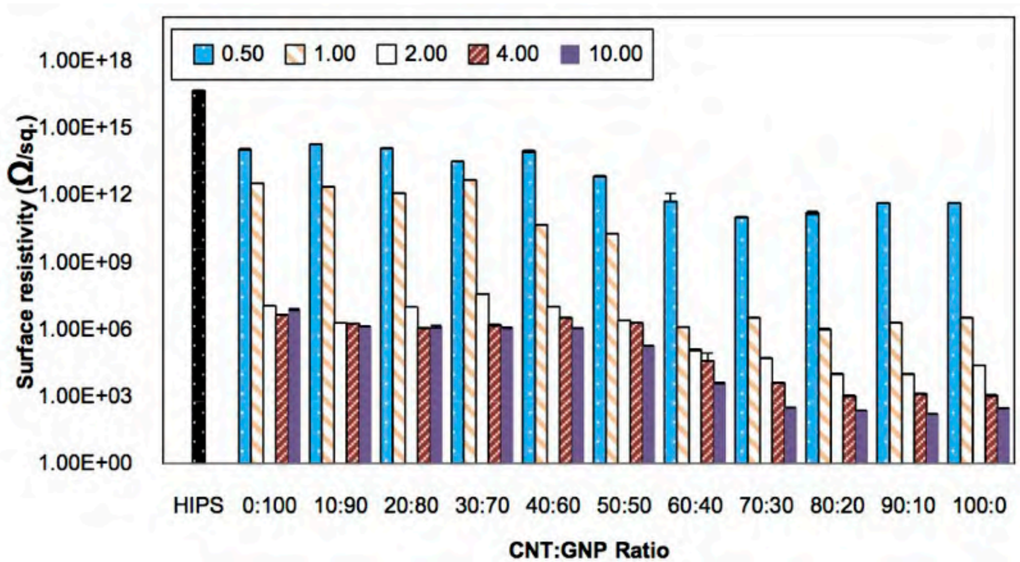
Thermoplastics: Mechanical Strength



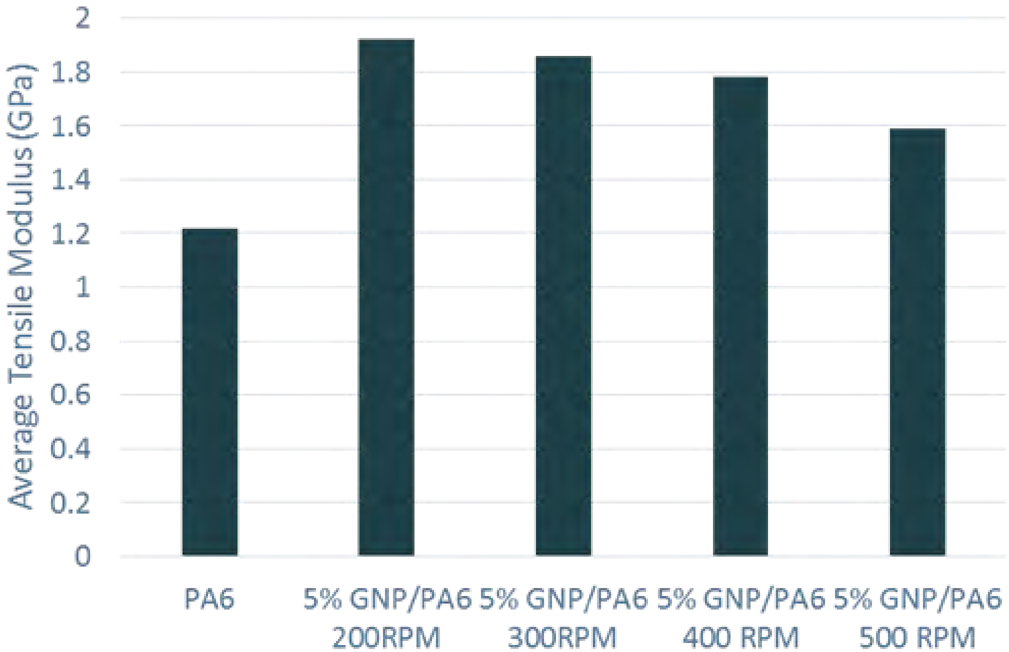
Thermoplastics: Conductivity



HIPS Resin with hybrid (functionalized) CNT/GNP filler – 10% masterbatch loading. Conductivity is good enough for the sample to act as a current limiting resistor for an LED.



Thermoplastics: Key Lessons



Injection moulded samples tensile tested at Element Materials Technology.

Optimum screw speed of 200RPM.

57% increase in tensile modulus.

73% increase in tensile strength

45% increase in elongation at break

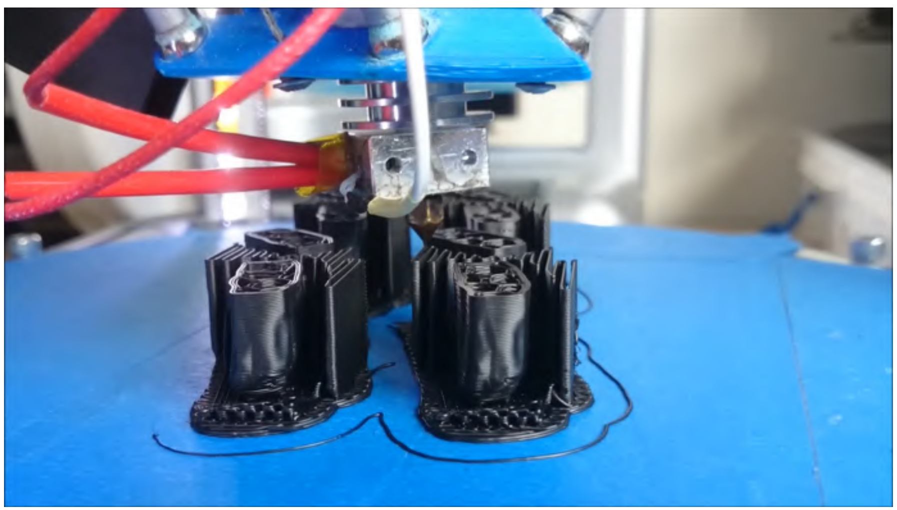
1. **Choice of material is important;**
2. **Choice of functionalization is important;**
3. **Even the choice of equipment is important;**
4. **Hybrid (CNTs+GNPs look quite interesting;**

Work funded by The Department for Transport – Transport Technology Research Innovation Grant (DfT T-TRIG).

Thermoplastics: PLA Filament

3D Printing of Graphene Loaded PLA filament

- PLA Masterbatch Compounded and Relationship Established with 3 Compounders
- Graphene Enhanced PLA Filament Extruded and Relationship Established With Extruder
- Filament Supplied to a Range of 3D printing Companies
- Product launched in September 2016 and available at http://shop.3dfilaprint.com/haydale-graphene-industries-plc-367-c.asp
- Further Work Ongoing with Nylon, ABS and PP

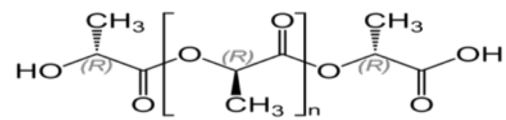


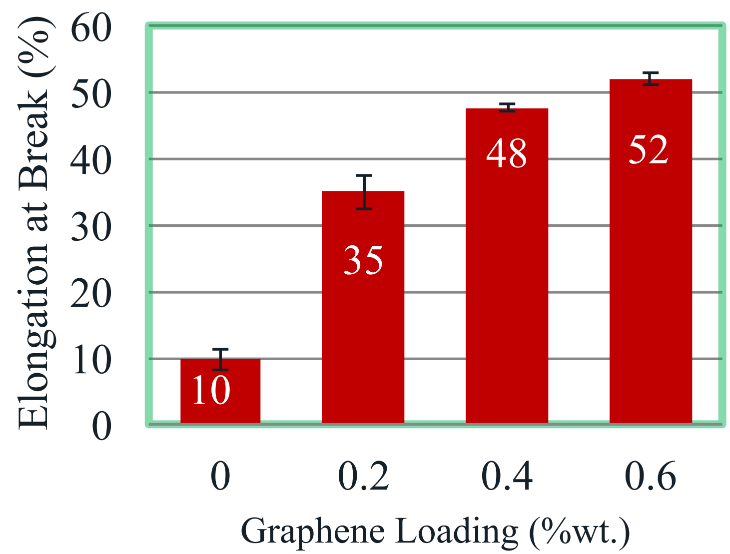
Printing of Graphene loaded PLA filament

HDPlas® Graphene+PLA Masterbatch

Graphene composite can enhance

- > 5 times elongation with no significant reducing its strength
- < 2 times OTR (Oxygen Transmission Rate) permeability
- Enrich permanent Anti-static property
- Increase Thermal Resistivity
- Economical cost of production
- Environmental friendly.





HDPlas® Graphene+PLA Masterbatch

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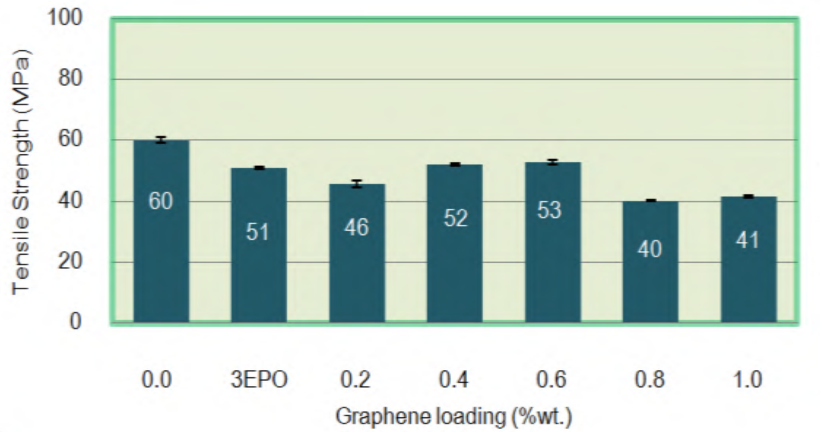
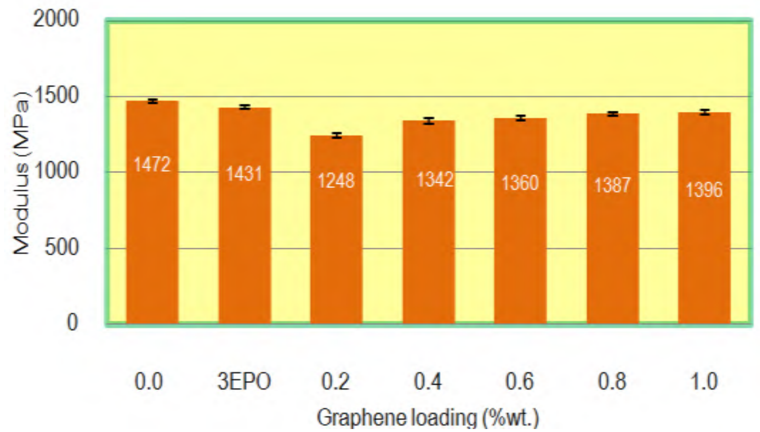
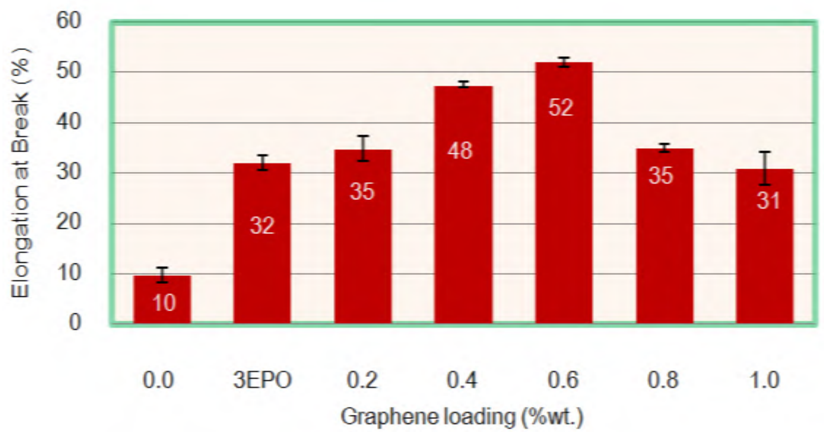
Tensile Strength



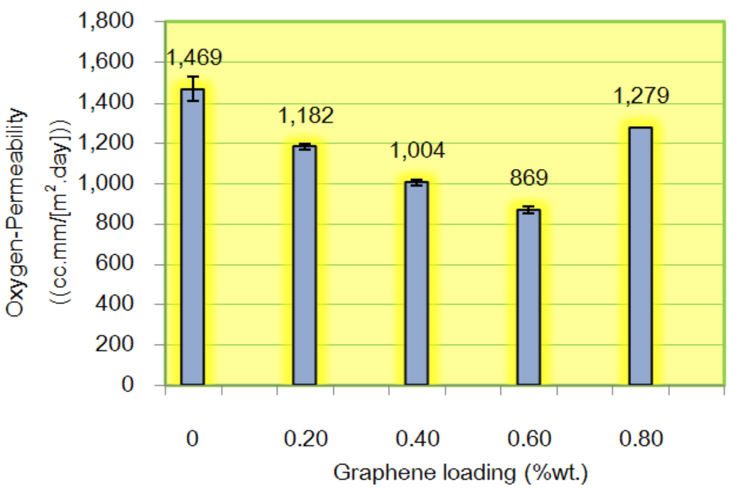
Tensile Modulus



Elongation at Break



Oxygen Permeability



THE FUTURE IS... POSSIBLE

SUMMARY

In summary, the addition of graphene (and other 2D nanomaterials) to polymers and composites can:

- Enhance the mechanical properties of the materials
- Increase the thermal conductivity of the materials
- Increase the electrical conductivity of the materials

However, in order to realise these benefits, it is necessary to be able to select the correct “type” of nanomaterial for the property improvements that are specified in the product design and to be able to impart a degree of functionality that allows the selected nanomaterial(s) to engage positively with the polymer.

It is this ability to be able to:

- select the correct nanomaterial(s),
- design in and impart the type and degree of functionalisation and
- supply materials in industrially relevant quantities

that gives Haydale its competitive advantage in the market.