APPLIED GRAPHENE MATERIALS

TECHNICAL APPLICATION NOTE

Colour

Graphene Pigment

Contents

1. Introduction

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

Applied Graphene Materials UK Ltd 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 in the area of colour/pigmentation.

The addition of graphene alone by a **G***enable***®** dispersion 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, Part 2 & Part 3.

The **G***enable***®** range of dispersions have been developed to enhance the anti-corrosion performance of coatings on steel and aluminium substrates by the use of a patented active, non-metallic anti-corrosion additive (discussed in further detail in AGM's **G***enable***®** Product Guide).

This technical application note describes in further detail how the addition of graphene impacts the colour performance in epoxy (EEW=250g/eq) based coatings systems. The work demonstrating how colour strength is given to resin dispersions using graphene as a black colour pigment compared to traditional tint pigments such as carbon black.

The **G***enable***®** 1000 series consists of A-GNP10 graphene stably dispersed into a range of media including epoxies, solvents and water and the **G***enable***®** 1200 series consists of A-GNP35 stably dispersed into the same range of media.

2. Comparing the Colour Attributes of A-GNP10, A-GNP35 and Carbon Black

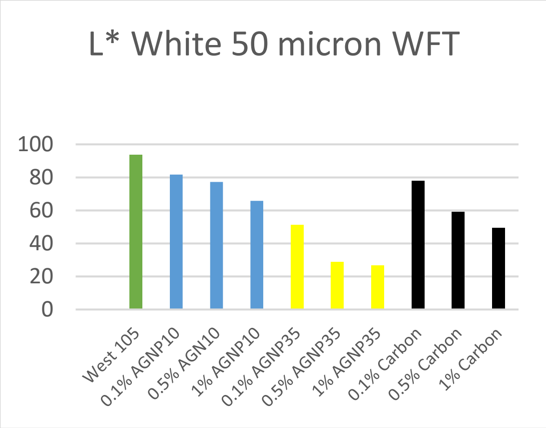
The colour data was generated to compare how the addition of A-GNP10, A-GNP35 and carbon black to an epoxy affected its colour attributes.

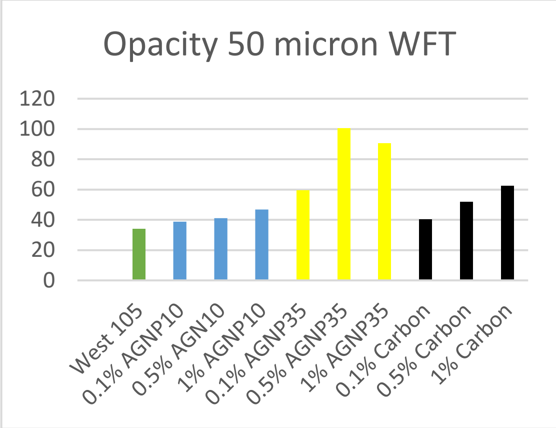
A-GNP10 and A-GNP35 graphenes were compared in terms of optical density and mass tone (also referred to as mass colour: the full colour of pigment or coatings) compared to an Ensaco 250 G Carbon Black.

L* and opacity measurements were taken of the graphene and carbon black in an epoxy (EEW=250g/eq), where the samples contained graphene and carbon dispersions at 0.1%, 0.5% and 1% wt/wt at differing wet film thicknesses.

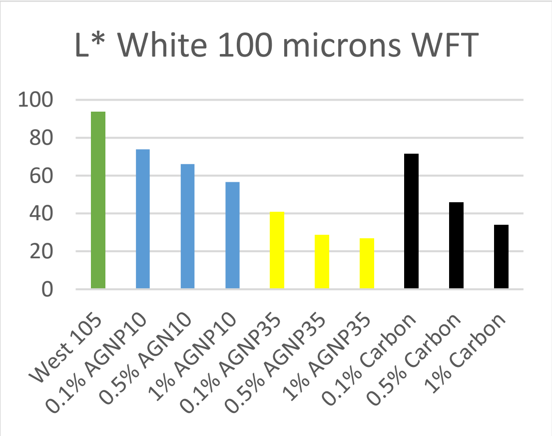
The test pieces consisted of epoxy and graphene or epoxy and carbon black alone.

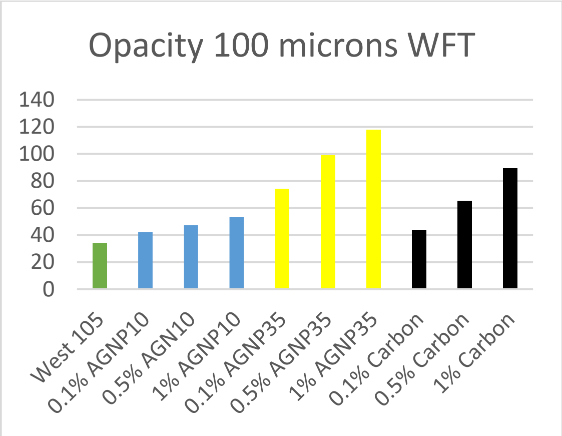
2.1. L* and Opacity Measurements at 50 microns WFT





2.2. L* and Opacity Measurements at 100 microns WFT

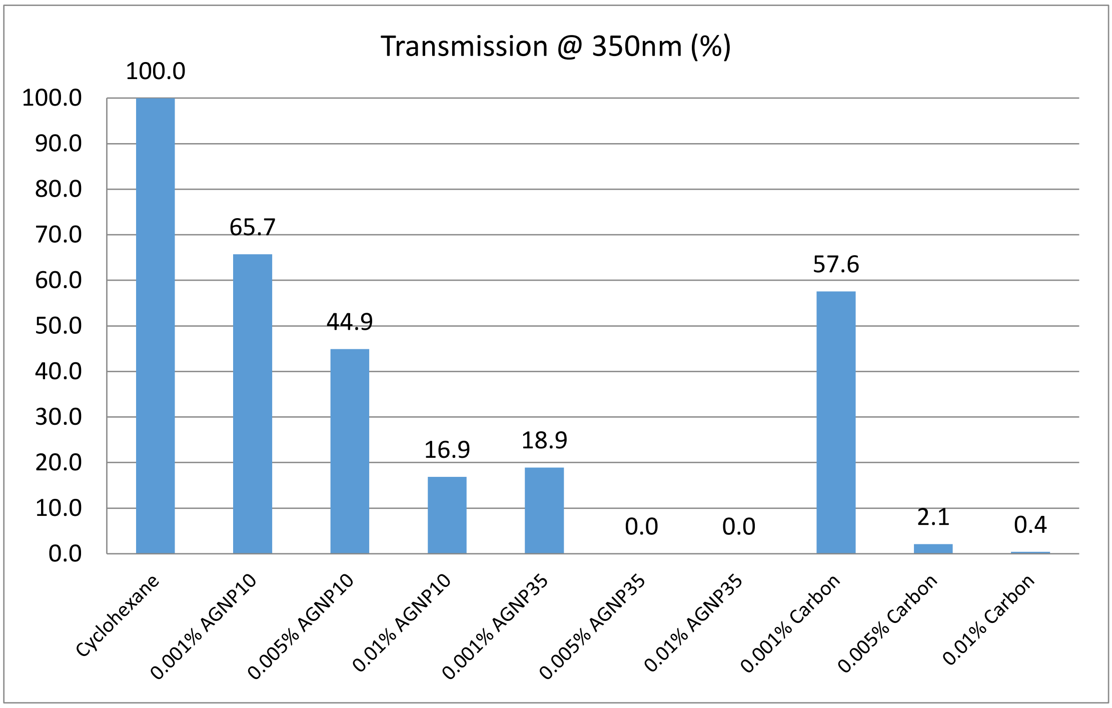




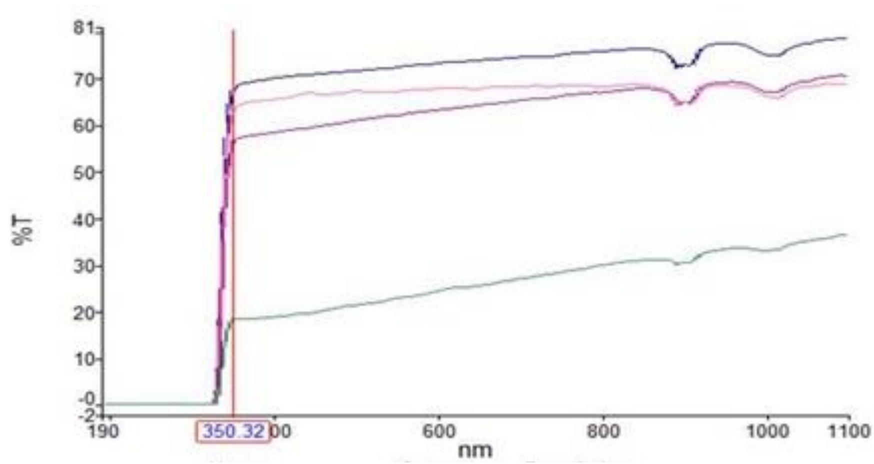
2.3. % UV Transmission at 350nm

For practical terms, results were taken at the point where the samples generally showed a complete drop off in transmission; in this case at a wavelength of 350nm.

The A-GNP dispersion samples (at 0.1%, 0.5%, 1% wt graphene) used to generate data for L* and opacity were completely opaque to UV light, and as such did not generate relevant spectra. To enable measurable transmission data to be generated the original A-GNP samples had to be further diluted to 1% wt concentration of the original dispersion.



2.4. UV Transmittance at 0.001% wt Graphene v Carbon Black Comparison



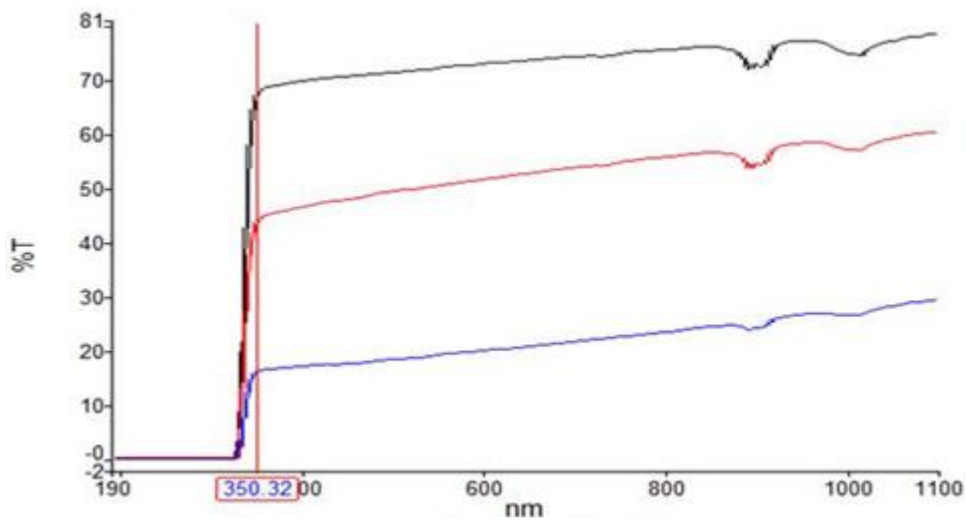
Sample Name

0.001% wt Carbon Back

0.001% wt A-GNP10

0.001% wt A-GNP35

2.5. UV Transmittance for A-GNP10 Loading Comparison



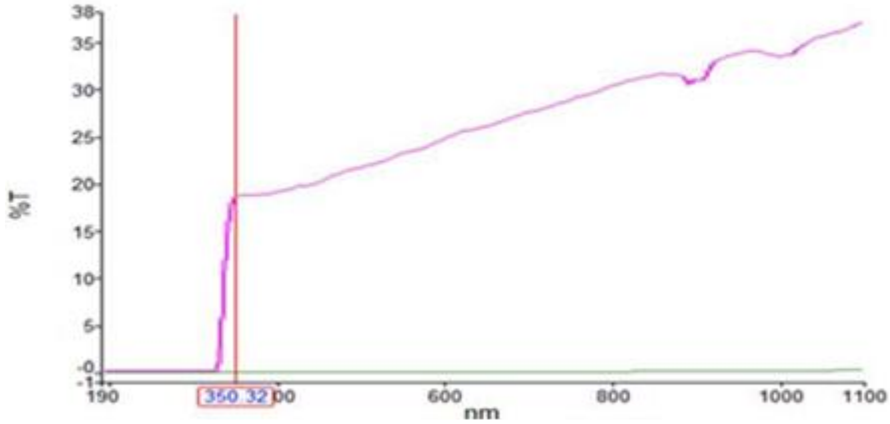
Sample Name

0.001% wt A-GNP10

0.005% wt A-GNP10

0.010% wt A-GNP10

2.6. UV Transmittance for A-GNP35 Loading Comparison



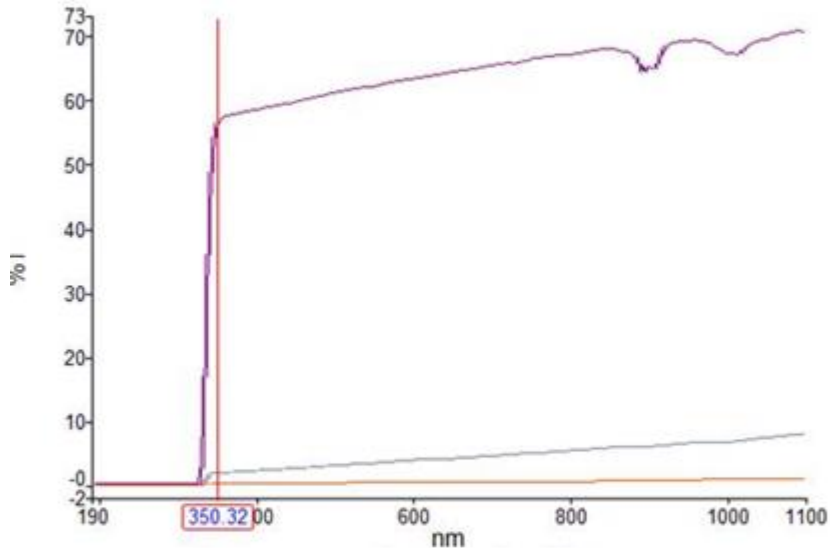
Sample Name

0.001% wt A-GNP35

0.005% wt A-GNP35

0.010% wt A-GNP35

2.7. UV Transmittance for Carbon Black Loading Comparison



Sample Name

0.001% wt Carbon Black

0.005% wt Carbon Black

0.010% wt Carbon Black

3. Summary Table Comparing the Colour Attributes of A-GNP10, A-GNP35 and Carbon Black

Attribute	Wt	A-GNP10 compared to Carbon Black	A-GNP35 compared to Carbon Black	A-GNP35 compared to A-GNP10	Compared to itself
Hiding Power	0.1%	Similar	Similar		
	0.5%	Less effective imparting colour	More effective at tinting a dispersion		
	1%	Less effective imparting colour	More effective at tinting a dispersion		
L*	0.1%		At least as effective as 1% CB at film thicknesses as low as 50 microns		
	0.5% to 1%				Increasing loadings of A-GNP35 doesn't significantly reduce L*
UV Transmittance	0.001%			0.001% A-GNP35 is equivalent to 0.01% of A-GNP10	
	0.005%		Is significantly more opaque than 0.01% Carbon Black		

4. Impact of Dispersing Resin on the Colour Attributes of A-GNP10 and A-GNP35

The **G***enable*® range consists of graphene nanoplatelets stabilised in an aldehyde based dispersing resin which itself has an impact on colour. The impact on colour was measured by drawing down aqueous dispersions on to colour cards and the following colour measurements were taken.

0.5% A-GNP35 in:	L*	A	B
Water only	26.24	0.52	1.16
10% Dispersing Resin + 90% Water	18.23	2.33	0.99
20% Dispersing Resin + 80% Water	17.63	2.53	1.02
30% Dispersing Resin + 70% Water	17.65	2.41	1.17
40% Dispersing Resin + 60% Water	17.3	2.63	1.53
50% Dispersing Resin + 50% Water	16.63	3.17	1.9

10% A-GNP10 in:	L*	A	B
Water only	5.75	17.85	-8.04
10% Dispersing Resin + 90% water	6.07	17.27	-9.18
20% Dispersing Resin + 80% water	2.31	19.51	-12.11
30% Dispersing Resin + 70% water	2.36	20.65	-14.32
40% Dispersing Resin + 60% water	5.1	18.75	-9.51
50% Dispersing Resin + 50% water	1.06	9.74	-1.55

For dispersions of A-GNP35 in water at higher levels of dispersing resin a deeper/darker black was produced with a resultant drop in L* values.

For dispersions of A-GNP10 in water, there was not much change in the measured colour with and without the dispersing resin.

5. Summary

5.1. Colour Performance

At loadings of 0.1% wt/wt in dispersions there is no or very little discernible difference between the colour imparted by carbon black or graphene.

At loadings of 0.5% and 1% wt/wt A-GNP10 and A-GNP35 are more effective than carbon black at tinting a dispersion.

Increased loadings of A-GNP10 and A-GNP35 from 0.5% to 1.0% wt/wt does not significantly reduce the L* values obtained.

0.5% wt A-GNP10 and A-GNP35 are as least as effective as 1% wt carbon black.

0.1% wt AGNP35 is as effective as 1% carbon black at lower film thicknesses (50 microns) and only marginally less effective at higher film thicknesses (100 microns).

5.2. UV Performance

Even at 0.1% wt A-GNP graphene dispersions there is no observed UV transmission.

A-GNP35 shows significantly less UV transmittance than carbon black at the same loading levels, 0.5% wt of A-GNP35 shows 17 times lower transmittance than 1% wt of carbon black.

1% wt/wt of A-GNP10 is equivalent of 0.1% wt/wt of A-GNP35 in terms of transmittance.

Appendix 1: Definition of Terms and Test Methods used in Colour

A.1 Method to Measure Opactity

The ASTM D344 Test Method for Relative Hiding Power of Paints by the Visual Evaluation of Brush outs method was the basis used to measure opacity.

The percent value of opacity from the data collected was calculated using the equation:

Percent Opacity = (Black "L*" Value/White "L*" Value) x 100 = Optical Density

Mass Tone = Mass Colour = the full colour of pigments or coatings.

A.2 Method to Define Colour: LAB Color Space

Explanation of the LAB Color Space (or CIELAB Color Space)

Colour space is defined by the CIE (Commission Internationale de l'Eclairage) describing all perceivable colours based in the three channels based on one channel for Luminance (lightness) (**L***) and two colour channels (**a*** and **b***).

A major alternative to the LAB Color Space is the XYZ colour system, which has a disadvantage in that the colorimetric distances between individual colours do not correspond to perceived colour differences. For example in the figure below, a difference between green and greenish-yellow is relatively large whereas the distance between blue and red is quite small. The CIE solved this problem in 1976 with the development of the three-dimensional Lab Color Space (or sometimes referred to as CIELAB Color Space).

In this model, the colour differences which you perceive correspond to distances when measured colorimetrically. The a* axis extends from green (-a) to red (+a) and the b* axis from blue (-b) to yellow (+b). The brightness (L) increases from the bottom to the top of the three –dimensional model. (From www.linocolor.com)

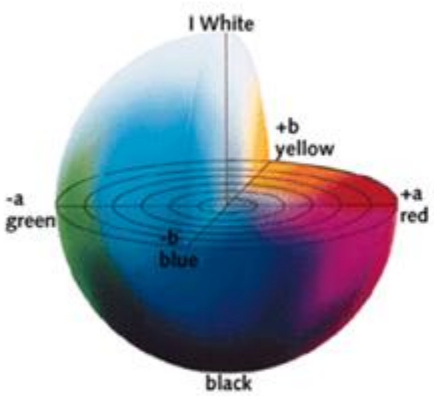


Figure: The CIELAB color space (from www.linocolor.com)