haydale™

Industry Interaction Case Study

Haydale and P²CAR

"The use of advanced rheology techniques has enabled us to conclusively demonstrate the benefit of the Haydale Plasma process enabling better and more stable dispersions as well as the added functionality for sensors and conductive inks. We are working with the WCPC to further refine the approach for process control and quality assurance."

Ray Gibbs
Chief Executive Officer
Haydale Ltd.

Using academia to unlock answers for Industry

The academic team at Swansea University have used their advanced rheological approach to help industry understand how the functionalisation of ink particles will change the properties and print performance of their inks. This ability to predict process performance highlights one of the ways academia-industry collaborations can benefit businesses. As the study and findings below illustrate, this academic input has provided Haydale with critical information in a time and cost-effective alternative to print trials.

The use of rheology to determine the effect of functionalisation of graphene nano platelets (GNPs)

Graphene nano platelets are small high aspect ratio particles comprising of several layers of graphene. They are typically 50nm thick by 5µm, which gives them a high surface area to volume ratio and a tendency to agglomerate. Adding functional groups to the surface of the GNP enables them to be better dispersed and to provide additional functionality. Functionalised GNPs (f-GNPs) were created using Haydale's proprietary plasma process.

It has been hypothesised that the benefits seen by adding the functional groups to improve the dispersion of the particles when in solution, is by increasing the repulsive force between the platelets and promoting particle to polymer interactions. The impact of functionalisation on dispersion can be identified using the advanced rheological approach developed in the ARPLAE project, which included equilibrium viscosity, small amplitude oscillatory shear (SAOS) and controlled stress parallel superposition (CSPS). The aim of the study was to show the effect on the rheology caused by changing the functionalisation on GNPs in a screen printing ink.

f-GNPs with 4 different functional groups (NH_3, COOH, Ar and O_2) were dispersed in TPu resin to produce a range of screen printing inks to be measured rheologically and by printing trial. The inks were tested rheologically using a Malvern Kinexus Pro rheometer and the standard WCPC testing procedure which takes measurements of both the viscus and viscoelastic properties. The print trials were performed using a DEK 248 automatic screen press and a single set of printing conditions. The prints were measured electrically using a 4-point resistivity probe and the topography was measured using a VEECO white light interferometer.

The aim of the rheological experiments was to examine how different functional groups

changed the dispersion of the nano-particles within the resin. The concentrations of particles used in the inks was varied from semi-dilute to concentrated range. A higher equilibrium viscosity indicated better dispersion as the high aspect ratio GNP particles better maintain their high surface area increasing their interactions with the fluid and restricting their movement relative to each other. The best performing functional group was NH_3 followed by COOH, then O_2. The inks were also tested for their non-Newtonian properties using the small amplitude oscillatory shear (SAOS) and Controlled Stress Parallel Superposition (CSPS) methods. The SAOS and CSPS data highlighted the impact of increased loading in the concentrated regime with the lowest phase angle leading to worst quality print despite the better particles dispersion. The order of the different functionalisation also fits the polarity of the different groups and their affinity to the polar polymer being used, with NH_3 being the most polar and Ar being the least. An increased polarity and matching of the functional groups for the polymer being used improve the dispersion of the particles. The importance of the particles being dispersed was seen in the printability tests where the NH_3 shows an improvement over the other materials in terms of surface roughness and sheet resistance in the semi-dilute regime.

In summary, there was a measurable difference in both the rheology and print performance of inks formulated with GNPs which had been plasma treated to attach different functional groups. When the results for the different functional groups were compared the same trend was seen in both the rheological and print performance, with the NH_3 being best, followed by COOH, then O_2 and finally Ar. This trend also represented the change in the polarity of the functional groups being attached and their affinity to the TPu. Whereby a higher polarity and affinity to the polymer produced an improved dispersion of the f-GNPs in the resin and improved print performance.

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For further information on this study, please contact j.m.claypole@swansea.ac.uk