Effectiveness of graphene nano-platelets in composites

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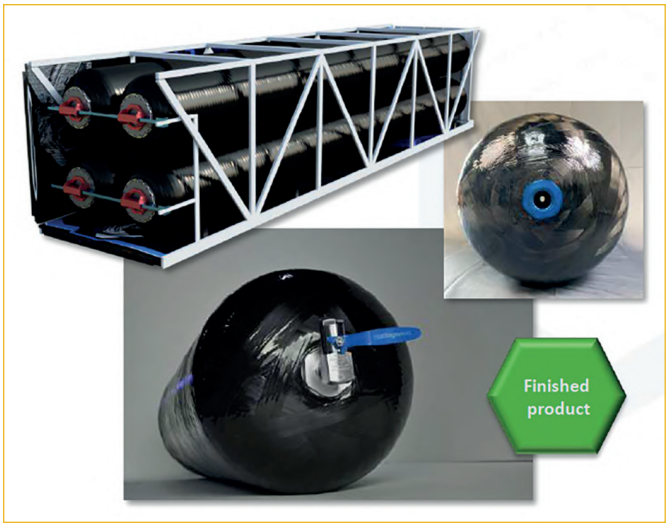
Graphene has become a fascinating material since its isolation in 2004. From its multiple different formats, including single-layer materials to few-layer structures, the performance attributes of the materials available to the industry can be outstanding, hence making them a material of interest. One of the challenges with graphene is how to use it effectively in a range of applications to bring targeted benefits to a host material.

Composites by nature are a combination of materials, including fibres oriented in a range of patterns and assemblies, resins and their catalysts, tougheners and other nano-materials, which together can yield remarkable performance.

The targeted inclusion of graphene in nano-platelet form represents an opportunity to further boost some of these attributes and enhance the whole composite material beyond its current scope.



Graphene plays a determinant role in hydrogen storage vessels production

What do we mean by nano-platelet form?

In order to be used effectively, graphene materials have to be in a form whereby they can be added to the composite material. Manufacturing methods for graphene can be wide-ranging, but the materials of practical interest are typically 2D structures of a few carbon layers in thickness (nanometre dimensions) and micron-sized in the X and Y planes. These materials in physical form, therefore, are plates of carbon with a very high aspect ratio and a high specific surface area, which have the potential, when properly integrated, to impart mechanical performance advantages, electrical conductivity, thermal attributes, barrier performance and chemical resistance. How these materials are added to a composite and where they sit within the composite structure will often determine the effectiveness of the material.

Applied Graphene Materials (AGM) offers different types of graphene nano-platelets (GNPs), which represent a breadth of material attributes, including the degree of crystallinity, surface functionality, particle size, layer count, inherent electrical and thermal conductivity. Each of these characteristics can impart performance gains when used appropriately in a host material. The key challenge to effective use in the liquid matrix systems often found in composites for industrial, construction, automotive and aerospace applications is the effective dispersion of the GNP material to enable it to be easily

and consistently added to the mix in a production setting.

Dispersions: what are we seeking to achieve?

Within most practical applications for graphene, the materials engineer is looking for a consistent, repeatable array of separated platy materials surrounded by matrix materials to achieve a certain performance envelope. As a parallel, in a composite, the mechanical performance is realized from the fibres being efficiently coated with the matrix resin to effect load transfer. Similarly, other additives need to be well dispersed through the matrix of the composite material to be effective. The same can be said for the use of GNPs for graphene to offer a performance advantage – the target being to achieve a uniform array of individual platelets through the system. This is why the pioneering work at AGM is so important. Dispersion technology for GNPs is critical to their successful use. Why? One of the key hurdles to overcome with the use of GNP materials in many host matrix applications is the inherent ability of graphene to self-stack, leading to agglomeration of the platelet structures. GNP manufacturers go to great lengths to produce separated platelet structures. Over time, these can re-agglomerate, however, making the material far less effective than desired and practically difficult to use. Dispersion solves this problem for the end user, in addition to dealing with the environment, health and safety (EH&S) issues surrounding the safe use of nano-materials in many production settings. Having the materials dispersed and encapsulated is a major benefit.

AGM has found that the optimum means of introducing graphene nano-materials into a resin matrix to achieve a useful array of GNP structures through the matrix, or on fibre sizing, is to incorporate them into a pre-dispersion.
Thus, the company offers a range of graphene nano-platelet dispersions that can be diluted to suit the loading level required so that optimum performance gains are achieved. Offering GNPs in resins, solvents and other materials used in the composite system in question enables the end user to easily deploy the material in the final product. AGM offers a standard range of graphene dispersions in commonly-used materials, a green chemistry range and can also customize them to suit specific application types.

Graphene use in composites

Once in an appropriate dispersion format to suit the end use application, materials engineers can specify formulations to target specific advantages. Considerations in the use of the material and the determining effect can include:

- ***Mechanical attributes and morphology*** of the graphene platy material can have a profound effect on the mechanical performance of a composite to which it is added. GNPs can range in form from flat, shard-like plates to gently folded, tissue paper-like structures.

- ***GNP loading level*** needs to be optimized to add the attribute desired. This can be surprisingly low as a percentage addition to positively impact mechanical attributes. However, care should be taken to avoid adding too much material, as this can lead to a deterioration of mechanical performance. By contrast, electrical conductivity relies on percolation, so higher loading levels may be required if this is the primary purpose of using GNPs. Similarly, thermal conductivity is significantly determined by the loading level.

Focus

A growing market

According to a MarketsandMarkets research report, the global graphene market size is expected to grow from USD 620 million in 2020 to USD 1,479 million by 2025, at a CAGR of 19.0%.

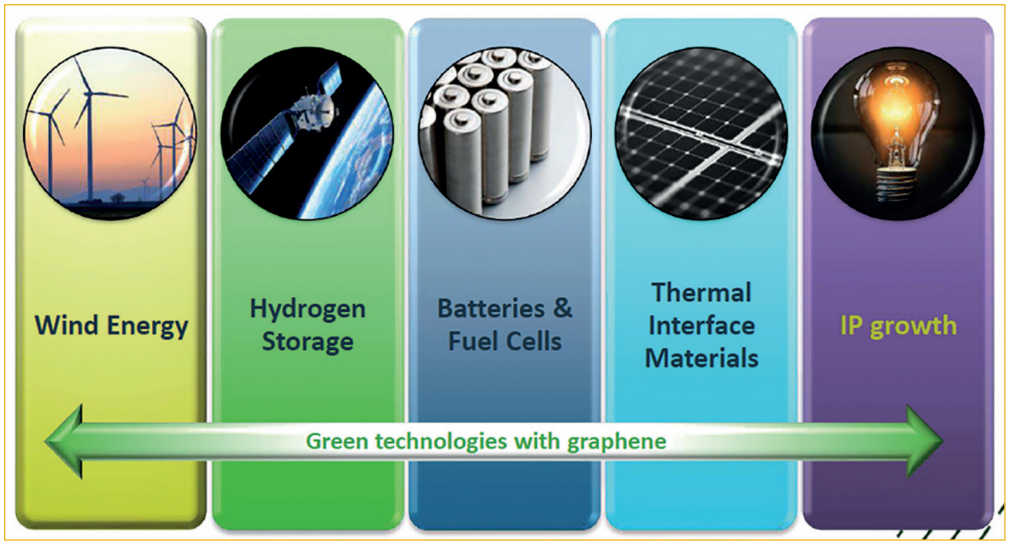
Over the past years, graphene manufacturers have strengthened their position in the global graphene market through expansions, partnerships, agreements, new product/technology launches, joint ventures, contracts, and mergers & acquisitions. R&D activities ongoing in the industry are creating cost-effective manufacturing technology for graphene. These growing R&D activities are expected to drive the graphene market during the 2020-2025 period.

An increase in the use of graphene may also be observed within the context of sustainable development. When used in coatings, graphene improves the lifespan of the products it reinforces. Its resistance to corrosion and chemicals makes it a great candidate for oil and gas pipeline production. Graphene-reinforced products are therefore more reliable and require less maintenance in the end. Finally, graphene plays an important role in the growing compressed air energy storage (CAES) market, including hydrogen. It provides increased capacity for resistance to pressure, and particularly fracture toughness.

Focus

APAC is expected to account for the largest market share in the graphene market during the 2020-2025 period

APAC accounted for the largest market share in the global graphene market in 2019. A number of graphene manufacturers in countries such as China, Japan, South Kora, India, and Australia are contributing to the growth of the regional market. These manufacturers are focusing on R&D activities in collaboration with various research institutes and universities for the development of graphene products. APAC has the highest number of manufacturers of automotive vehicles, electric batteries, and electronics components; these are the major applications where graphene is used. The presence of major end-use industries drives the graphene market in the APAC region.



Future technology roadmap followed by Applied Graphene Materials for a "greener" world

Focus

Graphene by application sector:
- Composites
- Paints, coatings, and inks
- Energy storage and harvesting
- Electronics
- Catalysts
- Tyres
- Others

- ***GNP particle size*** can also be important. Particle size can have a significant impact if resin mixes are to be filtered for infusion; smaller platelets may well be needed for such processing methods. Similarly, the fibre preform architecture itself may filter such included particulates, so particle size can be important here as well. If GNPs are to be added to a fibre size or used to coat a preform, the particle size of the graphene needs to be considered relative to the diameter of the fibre being coated.

- ***The functionality of the material*** can have a determining effect on dispersibility through to the degree of bonding to the host matrix. This in turn may affect mechanical performance.

- ***The dispersibility*** of different types of graphene with loading level can also have a profound effect on the viscosity of the host media, so care must be taken in material selection considerations, in order to maintain mixing and processibility practicalities.

Benefits

One of the key benefits in carbon fibre composites seen consistently with the addition of graphene nano-platelets is in Mode 1 fracture toughness. Hereby, the longevity of a composite matrix can be increased significantly through the effective use of low loading levels of well-dispersed GNPs throughout the matrix.
Prepreg materials are available where the matrix fracture toughness has been enhanced through the effective use of a graphene dispersion additive to the resin mix.
Similarly, end users such as Infinite Composite Technologies Inc. have made well-documented good use of GNPs introduced through dispersion additives.

In their case, the pressure cycling from liquid gases in Type V pressure vessels greatly benefits from the use of graphene in such systems.
Toughness improvements also benefit applications such as prepregs used in extreme sports goods.

The barrier performance of graphene in resin matrix systems is well documented from AGM's work in coatings applications. Significant improvements in the diffusion control of corrosive species in coatings can be dramatically altered with very low loadings of high-surface-area platelets.

There is little reason in principle why the same performance cannot be achieved in a composite matrix system.
Vapour transmission rates can potentially be reduced through a matrix of, for example, a composite chemical storage tank, a carbon pressure vessel or other composite structures susceptible to adverse moisture conditions and weathering. Wind turbine blades come to mind here.

Conductivity can potentially be enhanced with GNPs used in the matrix material. However, care should be taken in this instance to balance the higher loading level needs for either electrical or thermal conductivity and the lower loading level limits for mechanical performance.

Conclusions

GNPs offer a great potential for materials engineers to enhance the performance of their composite systems. From a range of attributes imparted through the use of graphene nano-platelets as an additive, the possibilities align well with the appeal of composites themselves for an ever-increasing breadth of applications.

Care needs to be taken to select the correct type of graphene for the application in mind. Critical to success is the dispersibility of the graphene nano-material in question into the material to achieve a well-ordered dispersion throughout the matrix. In this way, maximum effectiveness can be achieved in use of the material.

Finally, the materials and process (M&P) engineer must bear in mind the potential effect that a high-surface-area material addition can have on the process viscosity of the material being added to, and the downstream processibility of some systems, such as vacuum infusion of preforms.

Bearing all these considerations in mind, successful outcomes continue to be achieved with this new and interesting class of additives for composites, coatings and beyond. □

More information:
appliedgraphenematerials.com