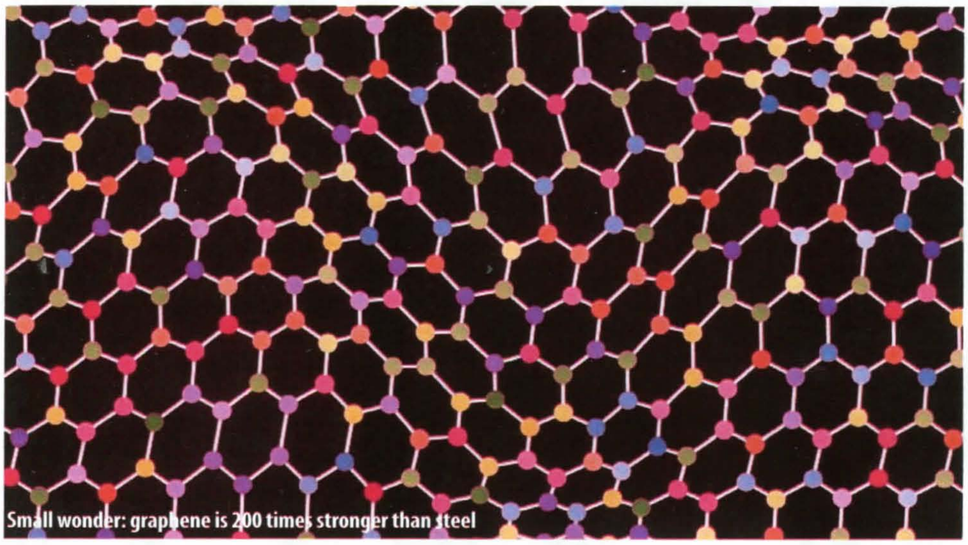


Flat carbon promises advanced plastics, and materials suppliers are starting to invest. But commercialisation of graphene demands answers to questions in production, processing and applications. By **Robert Stokes**

Graphene developers seek routes out of the lab

To listen to many researchers, the "wonder material" graphene will metaphorically transform base metal into gold. But what is in it for plastics manufacturers and what does the road ahead hold in store?

On the face of it, the material is impressive: graphene is a sheet of carbon, just one atom thick with the atoms arranged in a honeycomb pattern, around one hundred-thousandth of the width of a human hair, and 200 times stronger than steel. It is made from graphite, better known as pencil lead.

Graphene is one of the lightest but also the strongest and most thermally and electrically conductive materials known. It is transparent and provides a barrier to gas.

Many applications beckon, not least for advanced materials including plastics composites: foldable smart phones are just one flight of fancy that it has evoked.

Governments are backing it heavily, hoping to supercharge manufacturing industries.

The European Commission is planning to channel €1bn over 10 years into co-ordinated graphene research and commercialisation. The UK government has announced it wants to spend another £50m (€60.7m) to keep the UK at the forefront of graphene research, with the University of Manchester set to host a national institute of graphene research. Commercialisation of graphene by this route could arrive by late 2012.

Graphene's eventual isolation as a single layer in 2004 in a multicentre project led by Professors Andre Geim and Konstantin Novoselov at the University of Manchester saw them awarded Nobel Prizes in 2010.

Academics at the University of Minnesota (Minneapolis, the US) and The Petroleum Institute (of Abu Dhabi, in the United Arab Emirates) have analysed global research on graphene/polymer nanocomposites and reviewed it in the journal Macromolecules.

"Research suggests graphene has exciting potential as a multifunctional reinforcement in composites," said lead author Chris Macosko at the University of Minnesota, where he is Professor of Chemical Engineering and Materials Science and Director of the Industrial Partnership for Research in Interfacial and Materials Engineering.

Graphene film: this molecule is one atom thick but 100,000 atoms long in both lateral directions

"It can combine the benefits of layered silicates and carbon nanotubes," he said. Even an extremely small loading of graphene can significantly improve physical properties of host polymers.

The reviewers examined the reported pros and cons of current mechanical, thermal and chemical methods of making graphene from graphite and its oxide and of dispersing graphene in polymers. They described techniques for looking at the size and surface of particles and their dispersion in the matrix polymer, and went on to summarise the electrical, thermal, mechanical and gas barrier properties of graphene/polymer nanocomposites.

Good dispersion governs polymer nanocomposite performance. Take carbon nanotubes (CNTs), which may be chemically modified to aid dispersion but remain tangled as 3D bundles. While these can be disentangled with ultrasound, this often shortens the tubes, reducing efficacy.

Entangling is not an issue with 2D graphene, which can also be produced to retain useful chemical groups – epoxides and hydroxyls – to allow customisation. Being flat creates challenges though. Individual sheets may restack, reducing effectiveness, while their lightness raises issues of handling during processing and transportation. Researchers have countered restacking by using surfactants or by blending polymers before rather than after chemical treatment to potentiate graphene.

"The wider challenge is to reduce production and waste treatments costs to make graphene more commercially attractive," said Prof Macosko. "And standard operating procedures still need to be developed for potential health hazards."

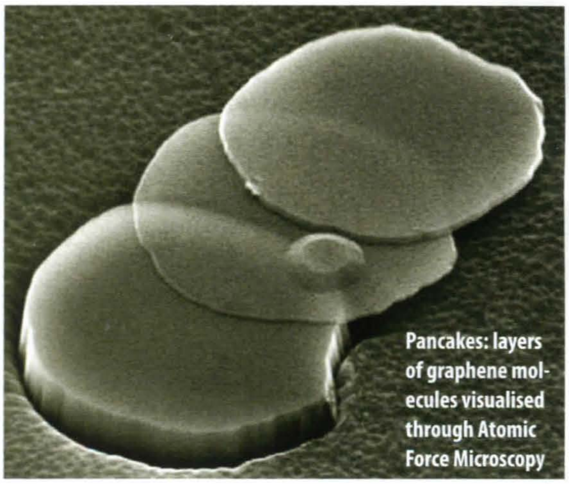
A spokesman for the University of Manchester researchers told *European Plastics News*: "Commercial graphene composites hinge on producing large quantities of graphene with one to three layers of reasonable size. Once this is available at competitive cost, graphene composites will become commercially viable."

Still, for every issue, science seems to have found or to be working on solutions. Some laboratories sell graphene for basic and industrial research, among them Graphene Industries, set up by University of Manchester. Its portfolio is expanding to include graphene from various sources and in different forms. It works closely with UMIP, the university's intellectual property company, which manages venture funds for commercialising graphene products and processes. It has partnerships with leading industries worldwide.

Some materials suppliers already produce graphene commercially while others are establishing research relationships to match scaled up production methods to market opportunities as they emerge.

Vorbeck Materials, based in Jessup, Maryland, US, has capacity to deliver ton-scale graphene branded as Vor-x and is a research partner of German chemicals giant BASF.

Attributes claimed for Vor-x illustrate what customers want from graphene in polymers and formulations. Vorbeck says Vor-x: greatly increases conductivity; improves the tensile modulus, strength and fracture toughness; improves protection against thermal degradation; reduces thermal expansion and improves dimensional stability; impedes solvent swelling; and



Pancakes: layers of graphene molecules visualised through Atomic Force Microscopy

increases resistance to gas permeation.

Vorbeck says Vor-x is easy to use as a dry powder or masterbatch formulation with standard melt processing equipment.

It is said to be compatible with a broad range of materials from natural, synthetic and silicone rubbers to polyesters, epoxies, and

'Commercial graphene composites hinge on producing large quantities of graphene with one to three layers of reasonable size'

acrylics. Composites and formulations with Vor-x are easily reprocessed and recycled, said a note from Vorbeck.

Vorbeck's graphene based ink, Vor-ink, is electrically conductive, which has opened new avenues for plastics electronics in smart packaging where it has cost advantages over silver based inks for labelling.

Cabot, based in Massachusetts, the US, is the world's largest producer of carbon black and has offered graphene nanoplatelets since last November after licensing IP from XG Sciences of Lansing, Michigan.

Cabot invests in product, process, and application development at its own research centre and is actively seeking development partnerships to accelerate commercialisation and position graphene as an advanced performance material.

"We're working to understand and see where graphenes can improve performance in plastics," said Gregg Smith, Cabot's director of new business development.

Carbon knights: Professors Konstantin Novoselov (top) and Andrew Geim (below) of the University of Manchester were knighted and won the Nobel Prize for their work on graphene

CREDIT All pictures courtesy of University of Manchester

"Our initial focus is on conductive applications where our goal is to achieve percolation in polymers at very low loadings. We have a long term view for development and production of graphenes. We continue to look at alternate approaches and technologies to understand performance properties in polymers and resins."

Thomas Swan & Co, based in Consett, the UK, a leading international manufacturer and supplier of high purity, single-wall CNTs, has struck a 4-year, £625,000 (€759,000) deal with the Centre for Research on Adaptive Nanostructures & Nanodevices at Trinity College Dublin, Ireland, to collaborate on industrial scale-up of consistent, high purity graphene production.

"We'll probably follow the same route as we did with carbon nanotubes," Thomas Swan's managing director Harry Swan told *European Plastics News* during the Graphene 2012 conference and exhibition, the largest such event in Europe, in Brussels in early April.

"We'll focus on the science and produce consistently good quality, stable manufacturing techniques then scale the right grade to match the right applications. It took ten years to get CNTs into profit and we expect the same kind of horizon with graphene."

Composites are a definite area of interest, he said.

Getting in on the ground floor makes sense, he added. "Companies that move earlier with research grade materials tend to be the ones that win later on."

The Graphene 2012 conference heard an update on the Graphene Science and Technology Roadmap being developed by Graphene Flagship – an initiative funded by the European Commission and involving 80 academic and industrial partners in 21 European countries – to advise on how R&D funding should be applied.

"The roadmap seemed sensible," said Harry Swan. "It follows a familiar curve from industrial and academic R&D to stable production and applications development. But the atmosphere at Graphene 2012 has been very much more commercialised than perhaps nanotubes were at the same stage. A lot of that is to do with Graphene Flagship focusing people on integrated routes to market." ■