FEATURE

From molecule to manufacture

Tony McNally

Inspired by the materials that helped astronauts survive Apollo 11's mission to the moon, Tony McNally has focused his career on developing new composites based on nanomaterials. The guiding principle underlying his research is that new composites must be useful as well as interesting.

Tony McNally is currently Chair and Professor in Nanocomposites at the University of Warwick, UK. Together with Professor Lord Bhattacharyya FREng FRS, he founded the International Institute for Nanocomposites Manufacturing (IINM) in 2014 and is serving as its first Director. The IINM is part of WMG (Warwick Manufacturing Group), which brings together research and teaching in engineering, manufacturing, and technology at the University. McNally leads a team of around 50 chemists, physicists, engineers, and modelers taking a 'holistic' approach to the manufacture of polymer composites. McNally's own focus is the processing of polymer nanocomposites, the functionalization of nanomaterial additives for composites, innovating the manufacture of functional nanocomposites, and applications in the electronic, defence, and automotive sectors, as well as medicine and drug delivery.

Before joining the University of Warwick, McNally served as Director of the Polymer Processing Research Centre (PPRC), the Medical Polymers Research Institute (MPRI), and the Advanced Materials & Processing Research Cluster at Queen's University Belfast. He also worked in R&D in the medical device and automotive industries, latterly at board level, leading collaborative projects with a range of multinational companies. He has published numerous papers, patents, edited two books, held a number of visiting academic positions in Europe and Australia, and served as an advisor/assessor to national and international funding agencies. He currently sits on the editorial boards of several journals.

Thank you very much, Tony, for being interviewed by *Materials Today/MPR*. What, or who, inspired you to embark on a career in materials science and composites?

Like many scientists I had some very inspiring and thoughtful teachers at school, but having grown up in the immediate two decades after the Apollo 11 first manned mission to the moon in 1969, I remember being fascinated by and thinking about how astronauts could survive in such a harsh environment as space. In particular, the concept of re-entry and the extreme temperatures the command module experienced captured my imagination. The key, of course, was materials science and engineering. Other outstanding technological achievements, such as Concorde, the SR-71 Blackbird, and the Space Shuttle, cemented my interest in materials science and engineering. The year before I graduated, carbon nanotubes had been identified and by the time I had completed my PhD in 1996, there was increasing interest in composites of polymers with nanoparticles having at least one dimension on the nanoscale (<100 nm) – polymer nanocomposites.

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What are your current research interests?

My current research interests are focused on melt processing of polymer nanocomposites; functionalization of nanoparticles, including the use of ionic liquids to modify layered silicates, covalent/non-covalent functionalization of carbon nanotubes and graphene(s) using grafting to and grafting from strategies; polymer nanocomposite drug delivery; composites of polymers or metals with carbon nanotubes (Fig. 1), graphene or graphene oxide (GO), and nanowires; the use of magnetic and/or electric fields, solid-state, and melt processing techniques to orientate nanoparticles in polymers; and ionic liquids as functional additives for polymers and mechanochemistry. While my research is rooted in fundamental engineering science, the target is functional composite materials that can be readily manufactured into products in high volumes.

Is there a piece of research during your career so far of which you are particularly proud?

It is difficult to point to one specific piece of research, but I think our understanding of processing-structure–property relationships of composites of polymers and nanoparticles is making a contribution. Our initial studies indicating the importance of secondary processing in controlling composite and product properties has drawn a lot of attention. Currently, we are looking at the use of external stimuli, such as magnetic and electric fields, to align nanoparticles in polymer melts during processing to develop multi-functional materials, but using high volume manufacturing techniques with a range of applications in mind. This could provide materials with different properties in different directions. Recent work on the use of ionic liquids (IL) as dual functional additives for polymers is also promising. For example, a single IL can act as both a plasticizer and an antimicrobial agent when incorporated into medical-grade PVC for use in catheters to fight antibiotic resistant bacteria (e.g. MRSA) and prevent biofilm encrustation. Much more recently we have undertaken a collaboration with Professor Stuart James in the field of mechanochemistry where we are using extruders to produce metal oxide frameworks (MOFs) – in other words, solventless synthesis.

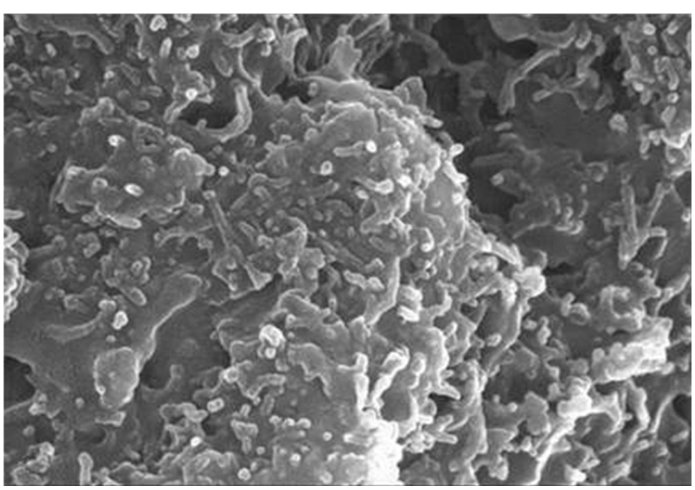

FIGURE 1

Scanning electron microscope image of a ternary melt mixed composite of polyethylene/polyaniline/multiwalled carbon nanotubes.

What are the potential applications of your research?

The applications are very broad if the challenges can be overcome. Currently, we have projects focused on aspects of batteries, fuel cells, biomedical devices, electronics, pharmaceutical technology, aerospace, automotive, security, packaging, and wind energy. By way of example, we work closely with the WMG High Volume Manufacturing (HVM) Catapult[1] on reducing the weight of components for automotive and other sectors such as offshore wind turbines. Our focus is functional materials that can be manufactured using high-volume production methods. Address this challenge and the applications will be numerous!

What are the aims and scope of the International Institute for Nanocomposites Manufacturing (IINM)? What do you hope it will be able to achieve?

When I'm asked this question, I usually start by paraphrasing Professor Peter Bruce FRS who, as part of a Royal Society delegation visiting WMG, said, 'It's easy to be interesting, but much more difficult to be useful'. This is certainly the case with regard most aspects of nanotechnology, and polymer nanocomposites are no exception. From my initial discussions with Professor Lord Bhattacharyya (with whom I co-founded the IINM), it was our aim to develop the area of polymer nanocomposites significantly by creating an Institute that would take a holistic approach to the production of polymer nanocomposites in high volumes. The results of which should be readily transferable to industry, from molecule to manufacture if you like. To this end, uniquely, in one new building we have synthetic chemistry laboratories where we can synthesize polymers and nanoparticles (organic and inorganic based), functionalize these particles using different strategies, small- and industry-scale extrusion and compounding, micro- and injection molding, compression molding, 3D printing capability, and extensive characterization facilities. I have also been lucky enough to be able to appoint a multi-disciplinary academic team (chemists, materials scientists, polymer processing and characterization specialists, and a multi-scale computational modeler), which is normally not possible in a traditional university science or engineering department. The scope of the IINM is to develop novel nanomaterials and composites but also innovate the science and technology associated with the manufacture of devices and components, embedding tailored functionality and properties. Ultimately, we hope to achieve tangible outputs that will benefit society – to be useful as well as interesting.

Where would you like to take your research in the coming years? What are the challenges or problems that you hope to address?

Specifically, with regard polymer nanocomposites there remain, despite more than two decades of intense research effort, some significant challenges to overcome. Firstly, the nanoparticle of interest, depending on the application, must be readily dispersed and distributed in the polymer matrix of choice. However, achieving this with industrially relevant melt-mixing techniques is a

[1] 'Catapults' are technical centers of excellence designed to bridge the gap between government industrial policy, academic research, and industry. The initiative was launched by the UK government in 2013/14 to focus on seven priority areas for the economy.

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nontrivial task. Regrettably, the tendency has been for researchers to take poorly characterized nanoparticles of interest and attempt to mix them into a polymer melt with whatever mixing device is immediately available in their laboratory, with little appreciation of the relevant processing parameters and, in many instances, the thermal stability of the nanoparticle. Second, as has always been the case with micro-composites but is even more critical on the nanoscale, the interface is all-important. Many properties of polymer nanocomposites are governed by the matrix-nanoparticle interface/interphase. Researchers need to ask how important is this interface? What are its properties? What are the mechanisms of compatibilization between polymer and nanoparticle surfaces? What strategies can be employed to functionalize a nanoparticle of interest without significantly altering its inherent properties, for example, electrical and thermal conductivity? One topic that has hitherto been poorly addressed is that the manufacture of a product from a polymer nanocomposite, irrespective of the level of nanoparticle dispersion, will require secondary processing of the as-mixed system. This can be a second thermo-mechanical cycle in the case of injection molding, or solid-state or quasi-solid state deformation in the case of thermoforming or blow molding. Furthermore, approximately 40% of all plastics sold are actually polymer blends. With a few notable exceptions, the localization of nanoparticles in immiscible polymer blends requires further study, as does the topic of nanoparticle-filled polymeric foams. The final challenge is for the computational materials science modeling community, as advances in multi-scale modeling of polymer nanocomposites have been limited to linear phenomena. Linking the macro- to the micro- to the atomistic and quantum levels requires the development of new methodologies, which are computationally efficient and validated experimentally. We are currently addressing all these challenges and more, and will continue to do so in the coming years. This also requires new approaches in experimentation to mimic industrial relevant processing. By way of example, we are developing a rig that allows us to deform samples biaxially *in situ*, and most importantly at the strain rates used in industry, in a synchrotron beam-line.

What have been the most exciting and important advances in the composites sector in recent years?

The increased use of conventional carbon fiber composites in civilian aircraft and more recently in the general automotive market is exciting. However, it is one thing to produce hundreds of aircraft a year, it is completely another to manufacture millions of cars per annum in a cost effective manner, a challenge that WMG is also addressing. With regard polymer nanocomposites, I think the key word is 'functionality'. The inclusion of nanoparticles with different inherent properties and the translation of these properties to bulk polymers will be important. There is a need for functional materials that can deliver electromagnetic, electromechanical, and biomedical functionality, especially if they can be produced in large areas (m^2) and volumes at low cost. This, combined with innovation in the manufacturing process, will provide significant advances. For example, the ability to control transmission and reflection of electromagnetic radiation in new ways would be exciting. Imagine a nanoparticle-filled thermoplastic elastomer that is as flexible as a rubber band but has the thermal conductivity of a metal, and that you could make meters of this composite per minute in any width or thickness required. There have also been exciting developments in composites used for structural health monitoring, self-healing, and shape memory. We continue to try and learn from nature where millions of years of evolution have a head start on us. We can only imagine the possibilities that biomimetics could bring to this sector.

What do you see as the major challenges facing the sector?

With regard to polymer nanocomposites, the first challenge is the supply of nanoparticles in the quantities required and, depending on the application, nanoparticles with low/no impurity content, low defect density, and that can be synthesized with a tailored geometry and surface chemistry which is thermally stable for melt mixing with polymers. Second, for high volume applications, there are the combined challenges of dispersing and distributing nanoparticles in polymer melts followed by an understanding of secondary processing–structure–property relationships. A further potential challenge is related to the toxicity, real or otherwise, and regulatory issues surrounding nanoparticles and their composites.

How do you think the research community, industry, funding organizations, and government can best tackle these challenges?

Researchers are addressing these challenges, however, too few are taking a holistic view. Most nanoparticles have been discovered, developed, or identified in chemistry and/or physics laboratories, as one would expect. The focus on composites in these groups typically involves solution mixing with traditional organic solvents – but this bears no relevance to how polymer nanocomposites would be manufactured by industry. Chemists and physicists must engage more with polymer technologists and engineers. As has been the case for other functional materials, certainly in the UK, I think funding agencies with and without government should have focused calls for manufacturing polymer nanocomposites. While the UK has internationally leading polymer chemistry groups (for example at the Universities of Warwick and Sheffield), considerable investment in infrastructure in polymer processing and engineering laboratories is urgently required in the UK. This was addressed in Germany and France in the past and more recently in Austria. Indeed, I've just returned from a meeting at the Indian Institute for Science, Bangalore where the government of India announced their plans to increase the number of CIPET centres for polymer engineering and technology from 23 to 50 by the end of the decade.

Where do you think the sector will be in ten, twenty, and fifty years' time?

This is an impossible question to answer, but the development of multi-functional composite materials is still in its infancy and the real excitement lies ahead. At this early stage, and with such potential for this sector, I'm reminded of Albert Einstein's quotation, 'Imagination is more important than knowledge'. However, we must take a holistic and multidisciplinary approach and at every stage consider 'molecule to manufacture'.

Further information

http://www2.warwick.ac.uk/fac/sci/wmg/about/

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