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Nanocomposites as Materials Bearing Ultra-Grade Properties

Shane Laverty
First-Year Student (B.Sc. Nanoscience)
College of Physical and Engineering Science, University of Guelph, CANADA

In the field of material science, composite materials consistently exhibit superior properties over the component parts from which they are made. This characteristic provides new possibilities for the synthesis of novel materials. Nanocomposites are a recent addition to this group, but are emerging as a leader in the field of material science, where their unique properties have allowed scientists to surpass the limits of today's materials. Two key examples explained here are graphene nanoribbons and their ability to increase structural integrity of polymer, ceramic and metal composites, and a biodegradable graphene-amyloid fibril composite which retains up to 98% shape memory through changes in ambient humidity.

A nanocomposite is a material in which nanoparticles have been added to the molecular matrix of the previously existing particles in a substance to alter the properties of that substance (Camargo, Satyanarayana, & Wypych, 2009). The most significant differences between standard composite materials and nanocomposites is the ability to manipulate certain quantum effects in the material, such as quantum confinement, and the high surface area-to-volume ratio of its molecular structure (Ajayan, Schadler, & Braun, 2003). These abilities play a very important role in both the nanoscopic and macroscopic properties of the composite, providing it with an advantage that standard composites cannot match. The resulting advantage not only applies to the structural properties, such as strength of materials, but can also be applied to their optical, electrical, mag-netic, and chemical properties. Nanocomposites can be composed of many different constituent parts, where some are polymer based, some are organic, and others may be bulk-ceramic or bulk-metal composites.

Synthesis

The synthesis of nanocomposites can be accomplished in a number of ways to achieve different composite structures. All of these involve incorporating the nanoparticles into the original starting material. One particular method is the absorption of the nanoparticles into macroporous hydrogels. Macroporous hydrogels are substances that absorb large quantities of liquid through pores greater than 50nm in diameter (Molina, Rivarola, Miras, Lescano, & Barbero, 2011). The size and density of these pores can be adjusted through the altering of several variables involved in the synthesis of the gel, and they can be tuned to match a particular set of nanoparticles to be absorbed. After this process, the hydrogel may either remain wet or be dried, depending on the intended usage of the composite material. For example, this method was used to create a water-absorbent, flexible magnetic aerogel with extremely low density, high porosity and large surface area, using a cellulose-based aerogel embedded with cobalt ferrite nanoparticles (Olsson, Azizi Samir, Salazar-Alvarez, Belova, Ström, Berglund, Ikkala, Nogués, & Gedde, 2010). Such a substance would be useful in microfluidics devices or as an electronic actuator. Another example can be seen in the production of graphene metal-particle composites. To accomplish this, graphite oxide sheets are sonicated in a water solution and metal particles are then added to the solution (Xu, Wang, & Zhu, 2008). Once the metal

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College of Physical and Engineering Science, University of Guelph, Canada.

particles bind to the separated graphite oxide sheets, the sheets undergo reduction and become metal-particle graphene composites and the metal particles on the new graphene sheets prevent them from aggregating together to form graphite again. Almost every composite has its own method of synthesis specifically tailored to its formation.

Applications

The broad range of applications available for nanocomposite materials is the real reason they have received so much attention. Because of the variety of combinations of composites, their applications extend from producing batteries with greater power output and longer lifetimes to grafting a nanocomposite scaffold onto a broken bone in order to accelerate growth and repair (Ajayan et al., 2003). Some of the most promising nanocomposites are carbon-based, exploiting the properties of its various allotropes including graphene and carbon nanotubes. These carbon nanocomposites have yielded breakthroughs in high strength-to-weight and high electrical conductivity materials and are among the most rigorously studied (Walker, Marotto, Rafiee, Koratkar, & Corral, 2011). Their properties of nanocomposite materials could be sufficient to – when industrialized – allow engineers to build objects or structures previously thought impossible, such as an orbital space elevator or superconductors that operate at room temperature (Scheike, Bohlmann, Esquinazi, Barzola-Quiquia, Ballestar, & Setzer, 2012).

More recently, bionanocomposite materials have garnered significant attention. For example, a bioinspired nanocomposite of amyloid protein fibrils and graphene sheets. It is based on the collagen matrix in bone, which is a composite material containing hydroxyapatite mineral platelets and the protein collagen (Solar and Buehler, 2012). In bone, collagen fibrils self-assembled with the mineral platelets, but the collagen fibrils were replaced with amyloid fibrils and the platelets with graphene sheets in the nanocomposite. The root of the inspiration came from the observation that the properties of the bone composite were clearly greater than the sum of their parts. The same observation was apparent in the inspired grapheme-amyloid fibril nanocomposite, which exhibited a property inherited from neither of its constituent parts (Li, Adamcik, & Mezzenga, 2012). The nanocomposite showed a mechanical response to change in humidity in terms of varying stiffness and ductility, and exhibited a shape memory effect with 98% shape recovery accuracy when the ambient humidity was oscillated. In addition, the composite also has potential variability in its mechanical properties depending on the ratio of graphene to amyloid fibrils in its structure. It is also responsive to enzyme activity, providing characteristic biodegradability and the potential for the composite to be used for several medical applications including biosensors and drug delivery.

Rather than a hybrid bio-synthetic material aimed at biosensor applications, graphene nanoribbon composites have gained attention for their incredible structural reinforcement in experimental materials. Graphene nanoribbons can be synthesized using gas-phase plasma etching to unroll multi-walled carbon nanotubes into graphene nanoribbons, which can then be used to create reinforced composite materials (Rafiee, Lu, Thomas, Zandlatashbar, Rafiee, Tour, & Koratkar, 2010). Rafiee et al. (2010) used this technique to create thermally-treated-graphene-nanoribbon reinforced epoxy polymer composites. These epoxy polymer composites are created by using the graphene as a nanofiller during the material synthesis, where the added nanofiller fills in the space between polymer molecules in the molecular matrix (Rafiee, Rafiee, Wang, Song, Yu, & Koratkar, 2009). When compared to epoxy polymer composites synthesized using more traditional multiwalled carbon nanotubes instead, the nanoribbon composite showed a roughly 30% increase in its Young's modulus and a 22% increase in its tensile strength (Rafiee et al., 2010). The importance of this comparison is that the nanoribbons are the same material as the multi-walled nanotubes, except that they are unfolded and flat. The reason for this difference is that when the nanotubes are opened up into nanoribbons, they attain a greater surface area and fit into the polymer matrix evenly, allowing for everything to be flush and bond strongly with each other. As a result, graphene nanoribbon reinforced polymer composites show considerable promise for high strength materials that could possibly be used for various aeronautic or structural applications.

Conclusion

Both the graphene-metal particle nanocomposite and the graphene-amyloid fibril bionanocomposite discussed produced a set of traits that were mutually unexpected and extraordinary. Very little is truly known about the diverse nature of nanocomposites as a whole, and they offer a wide array of possibilities and combinations waiting to be explored and exploited for their unique properties. They offer a number of opportunities to produce solutions to problems in materials science, whether it is for the purpose of building the world's most powerful battery or to create incredibly strong and light materials for use in everything from vehicles to homes. In time, many of the materials currently utilized for all manufactured products may be replaced with a nanocomposite of superior quality and ability, hinting at the significant degree in which nano-composites may soon affect entire populations internationally. In addition, they require materials that are no more complex than those currently in use, and only require a different mechanism of construction.

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