

Advance Polymer Nanocomposites in Automobile Sectors: A Review

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Abstract

In recent times, polymer nanocomposites have attracted a great deal of scientific interest due to their unique advantages over conventional plastic materials, such as superior strength, modulus, thermal stability, thermal and electrical conductivity, and gas barrier. They are finding real and fast-growing applications in wide-ranging fields such as automotive, aerospace, electronics, packaging, and sports. This book focuses on the development of polymer nanocomposites as an advanced material for textile applications, such as fibers, coatings, and nanofibers. It compiles and details cutting-edge research in the science and nanotechnology of textiles with special reference to polymer composites.

Keywords: Nanofibers; Thermal stability; Young's modulus

Introduction

Nanocomposites are similar to composites in that they are made from multiple materials. But whereas we can often see constituents of the latter, such as individual threads of carbon fibre woven together, the former is modified at a nanometric level, a range between micro and molecular dimensions equivalent to billionths of a metre [1,2]. Though the theory of nanocomposite construction was devised in 1950, very little commercial activity came as a result. In fact, it wasn't until Toyota Central Research Development Laboratories filed its own patent for a nanocomposite system in 1988 that the specific method of creating this material became clearer [3-7]. After extensive testing of different materials and proportions, Toyota's patent asserted that the mechanical properties of a polymer could be most effectively improved by stacking nano-scale sheets of a silicate between the molecules of the primary polymer. Following this development, Toyota launched its first nanocomposite product in 1993 in the form of a timing belt cover for the Toyota Camry [8,9]. This was followed from 2001 with larger applications such as bumpers, body panels and fuel tanks, while the technology has now expanded to reduce the rolling resistance of tyres, as well as provide ultra-hard protective coatings for paintwork, windscreen glass and headlamps. What's more, Toyota's work in revealing the possibilities of nanocomposites has helped to increase the variety of base materials that can be improved through nano technology. Applications outside of the automotive industry have now improved the output of batteries, reduced the healing time for broken bones, and made aeronautical products with incredible strength-to-weight ratios [10].

Comparative analysis between all composites

Based on the rule of mixtures (details to be discussed in Section 2.2), the fillers utilized should have high stiffness and aspect ratio. Under mechanical stress, these fillers share a fraction of load through stress transfer across the interface, hence improving the mechanical properties of the matrices. Micron-sized fillers such as metallic fibres and ceramic particles at 15–60 vol% are often needed to improve the properties of host polymers. Using nanofillers often results in a much lower filler fraction usually below 2 vol% for significant improvements to the matrix polymers. Of all the nanofillers reported to-date, graphene and CNTs have attracted extraordinary interests. According to the Clarivate Analytic database, the numbers of publications by keywords of “graphene composites”, “CNT composites” and “graphene CNT composites” reveal growing trends over the past 20 years. Similar

numbers of publications are seen for two groups of nanocomposites respectively containing graphene and CNTs from 2010 to 2013, but since 2014 graphene composites have attracted far more interests. Noteworthy is that the studies of polymers containing MWCNTs and graphene appear to have just started, and these should be more extensively investigated in the years to come.

Since reported by Iijima et al. in 1991, CNTs have been on the forefront of polymer nanocomposite research. The tubes have covalently bonded structure, high stiffness and strength yet certain flexibility. More importantly, CNTs have higher thermal and electrical conductivity than conventional filler such as carbon fibre and glass fibre; these unique properties make CNTs superior. The team led by Liquan Zhang at Beijing University of Chemical Technology have conducted extensive research of using MWCNTs for elastomers. They found that MWCNT bundles with the same alignment, orientation and reasonable surface defects for each tube can be directly incorporated into an elastomer matrix through melt compounding, inducing a relatively uniform filler dispersion and strong interfacial interactions due to silane-coupling. The resulting nanocomposites demonstrated high mechanical properties, thermal conductivity and antistatic performance. Through further scale-up, the nanocomposites demonstrated the most optimized comprehensive performance for automobile tyres, e.g. fuel efficiency and fatigue resistance.

Graphene, as first mechanically exfoliated from graphite by Geim and Novoselov in 2004, is a single atomic layer of sp² hybridized carbon atoms arranged in a hexagonal lattice. In a graphene sheet, each carbon atom contributes three of its four outer-shell electrons by hybridizing to form σ -bonds with three adjacent atoms in the sheet. The remaining electron contributes to a conduction band that extends over the whole sheet, which provides graphene with semi-metallic

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characteristics, explaining high stiffness, strength and electrical and thermal conductivity.

Referring to graphene that is oxidized by strong oxidizers and acids, graphene oxide is electrically insulating; it is prepared from graphite oxide consisting of carbon, oxygen and hydrogen in varying concentrations. Reduced graphene oxide means graphene oxide that is reduced by chemical reactions or thermal treatments, to remove oxygen atoms and to partially recover the conduction band over each sheet. Chemically modified graphene means graphene that is modified by chemical reactions, to obtain solubility or compatibility with polymer or other specific functions; chemically modified graphene in many cases is actually surface-modified, partially oxidized graphene. Other derivatives of graphene may include few-layer graphene and multi-layer graphene.

Few-layer graphene is actually graphene (nano)platelets (GNPs or GnP_s; each platelet below 10 nm in thickness). We now distinguish graphene nanoplatelets and nanosheets. Graphene nanosheets usually refer to monolayer or few-layer graphene who must have large lateral dimension, in comparison with the small lateral dimension of GNPs. In polymer processing, GNPs would be preferred over graphene nanosheets because (i) nanosheets are difficult to exfoliate and disperse in polymer melts and (ii) such a large lateral dimension cannot be fully utilized for reinforcement or toughening.

Conclusion

Fiber reinforced polymer (FRP) composites are noncrystalline and brittle. Therefore, a strengthening mechanism applicable for metals may not be suitable for polymer matrix composites because of the different failure mechanisms. In polymer matrix composites, the initiation of crack is possible either in the matrix or at the matrix/fiber interface. If the interface bond strength is sufficient enough to sustain the applied load, then the probability of crack initiation is more in the matrix as compared to the fiber. The crack propagates through the matrix and the fiber-matrix interface depending on the adhesive bond between the matrix and the fiber. Failure occurs by the gradual propagation of the microcrack in the composites. Different researchers

and scientists have adopted different manufacturing processes to incorporate nanoparticles or tubes into the polymer matrix (solution processing, melt processing, in situ polymerization, sol-gel process, three-roll shear mixing, mechanical mixing, ultrasonic tip sonicator, ultrasonic bath, and ultrasonic dual mixing). The effectiveness of nanoparticles is such that the amount of material added is usually only between 0.1% and 5% by weight. However, uniform dispersion of high concentration of nano-fillers in the polymer matrix is a challenge to both researchers and academia for commercialization of polymer matrix nanocomposite materials.

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