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Mini Review

Structural Elucidation of Carbon Nanofibers (CNFs), Carbon nanotubes (CNTs), and Graphenes (GNPs) - A Mini-Review

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Abstract

The current review focuses on giving a basic structural understanding of carbon nanofillers such as Carbon Nanofibers (CNFs), Carbon Nanotubes (CNTs), and Graphene Nanoplatelets (GNPs) and their significance in developing various polymer nanocomposites.

Introduction

Carbon materials exhibiting high performance and multi-functional applications have received much attention from researchers and industrialists [1,2]. Their promising implications have guided researchers to trigger their ideas to design innovative materials for future generations. Carbon-based fillers such as CNFs, CNTs, and GNPs have been introduced inside various polymers to fabricate different polymer composites for efficient reinforcement and enhanced physical properties [3]. Among various organic/inorganic filler systems, carbon-based fillers are significant due to their exceptional mechanical, thermal, and electrical properties [4]. They can significantly improve the neat polymer's properties where the uniform/improved dispersion of these fillers inside the polymer is realized. In this regard, encompassing structural information related to the carbon-based fillers (CNFs, CNTs, and GNPs) is indispensable. This review is dedicated to providing a complete understanding of carbon based fillers (CNF, CNT and graphene).

Structural Elucidation of Carbon Nanofibers (CNFs), Carbon Nanotubes (CNTs) and Graphenes (GNPs)

CNFs, CNTs, and GNPs contain a standard structural unit that is a hexagonal arrangement of carbon atoms similar to graphite structure. However, GNP, a single layer of graphite, can be synthesized simply by employing scotch tape on graphite [5]. In the hexagonal arrangement of carbon atoms, each carbon atom undergoes sp^2 hybridization and is left with one pure p_z electron. These sp^2-bonded electrons are highly delocalized and can impose exceptional electrical properties on CNFs, CNTs, and GNPs at room temperature [6]. Due to their remarkable electrical, mechanical, and thermal properties, carbon nanomaterials grabbed massive attention from the researchers to incorporate them into polymers for augmenting their implications in various sectors.

Carbon nanofibers are generally classified as ribbon, platelet, and herringbone based on graphene layers' orientation with respect to the central fiber axis [7]. Graphene layers are aligned parallel and perpendicular to the fiber axis in the ribbon and platelet CNFs, respectively, whereas, in herringbone CNFs, graphene layers are located in a crosswise manner. Herringbone and platelet CNFs are commonly employed for the fabrication of composites and catalytic implications as they can exhibit high surface area to that of ribbon type. One of the synthesizing methods of carbon nanotubes includes wrapping up the graphene layers in a cylindrical structure [4]. They are composed of covalently bonded carbon atoms in the form of hexagonal rings. Interestingly, carbon nanotubes are more reactive than graphene as they possess misaligned unhybridized p orbitals. Many investigations on CNTs, especially in polymer composites, came into the limelight after their discovery in the 1990's by Ijima [8]. CNTs are mainly categorized into two types; Single-Walled Carbon Nanotubes (SWCNTs) and Multi-Walled Carbon Nanotubes (MWCNTs).

Nevertheless, other forms of CNTs have been reported in the past [9], only single-layer graphene is enough to generate SWCNT, where the graphene layer is wrapped in the form of a cylinder. These tubes' diameter varies based on the modes of wrapping and is mostly within the range of 1-2 nm. Their endcaps and sidewalls mainly regulate the physical and chemical properties of these tubes. Besides, the tube diameter significantly affects their reactivity as it is directly related to the tubes' surface area and the partial nature of sp^3carbons imposed by the decrease in tube radius. SWCNTs can be assigned another name through chiral vector representation (n, m) to how to wrap/roll graphene layer to create CNTs where n and m indicate unit vectors in two different directions the graphene plane [9]. These chiral vectors can influence the mechanical, electrical, and optical properties of CNTs. Based on the relationship between these two chiral vectors, CNTs are further classified as armchairs (where n=m), zig zag (where n-m=0), and other forms come under chiral structures. Two famous models, called the parchment model (explained through wrapping of single graphene sheet) and Russian doll model (structure derived based on concentric graphene sheets), demonstrate the structure of MWCNTs. The interlayer distance of zig-zag tubes (3.52 A°) is slightly higher than the armchair tubes (3.4 A°), and it is a little complicated to estimate the interlayer distance in chiral tubes. Double-wall CNTs exhibit high flexural modulus than SWCNTs due to the additional layer present in them and greater toughness over MWCNTs because of their lower size. Overall length for both MWCNTs and SWCNTs varies from nm to cm.

Conclusion

Graphene is undoubtedly a rising star on the horizon of nanoscience and nanotechnology. This two-dimensional material reveals exceptional electrical, thermal, and optical properties among other carbon nanostructures have become a cornucopia of advanced science and new implications [10]. As discussed earlier, graphene contains hexagonal carbon atoms with a two-dimensional honeycomb lattice and is composed of sp^2 carbon atoms with a single atom thick structure. It has been considered that graphene can act as a building block for all the other graphitic carbon structures of different dimensionality. For instance, in the graphite structure, graphene layers are stacked on top of each other with a separation distance of 3.37 A°. Graphene is generally categorized based on its preparation methods; one is top-down graphene in which graphene is synthesized from graphite and its derivatives. Another one is bottom-up graphene, where graphene sheets can be produced from smaller molecules such as ethylene, Silicon Carbide (SiC), Carbon Monoxide (CO), etc.

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