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Application of carbon nanotechnology in conductive composites

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Abstract. Conductive composites play a significant role in today's world. Conductive composites made of composite conductive polymers are improved by adding conductive materials. Carbon nanomaterials have stable chemical properties, light weight and good conductive properties, so that they can be used as excellent fillers of conductive composites. In this paper, the principle and application of conductive composites in the practical scientific field are reviewed. Graphene, CNTs, activated carbon, carbon aerogel and their preparation methods in carbon materials are introduced, and their structures, advantages and disadvantages are analyzed. The application of carbon nanomaterials in conductive composites is discussed. It is found that carbon materials can significantly change the conductive and mechanical properties of conductive composites, and the performance of conductive composites can be improved. Finally, the shortcomings and prospects of the application of carbon materials in conductive composites are analyzed.

Keywords: carbon nanomaterial, nanotechnology, conductive composite.

1. Introduction

As the first element of the fourth group, carbon is the most important element in nature. Its $1s^2 2s^2 2p^2$ ground state electron configuration, special properties, and electronic effects of covalent bonds formed in crystals or compounds enable it to form a variety of carbon-containing nanomaterials with rich properties and functions, such as soccerene (C60), carbon black (CB), carbon nanotubes (CNTs) and CNTs (C60). Graphene (GE), graphite sheet (GNS), etc. According to the material dimension, the above carbon nanomaterials can be divided into zero-dimensional (0D, including C60 and CB), one-dimensional (1D, CNTs), two-dimensional (2D, GE) and three-dimensional (3D, GNS) carbon nanomaterials [1-3].

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Conductive composite material mainly stand for compound conductive polymer material, composed of polymer and diverse conductive substances through a certain composite way to make it conductive. The importance of conductive composite materials in production and life has gradually been highlighted. For example, photographic film prepared with conductive composite materials with new conductive functions and low surface resistance has avoided the performance decline caused by the electrostatic phenomenon. And to resist electromagnetic interference and radiation interference, it is also necessary to solve the shielding performance of the material. In this respect, the role of conductive composite materials is also very prominent. Due to the excellent conductive properties of carbon nanomaterials, they are often used as conductive fillers to fill polymer matrices to prepare polymer-based conductive composites [4]. On the one hand, the conductive performance of insulating polymer materials can be endowed by the composite of conductive carbon nanomaterials and an insulating polymer matrix. On the other hand, carbon conductive nanomaterials are generally a powder, which can be combined with the polymer matrix to give the material good workability and prepare conductive composite products of various shapes.

This paper discusses the physicochemical properties of carbon nanomaterials and the brief introduction of conductive composites. The advantages of carbon nanomaterials as conductive composites are discussed along with key prospects.

2. Overlook of conductive composite materials

2.1. Principles of conductive composites

There is a general rule that the material resistivity changes caused by the additional amount of conductive filler in polymer conductive composite materials; that is, when the additional amount of conductive filler is low, the material resistivity almost does not decrease with the increase of the addition amount of conductive filler, a small amount of conductive filler can make the resistivity of the material drop several orders of magnitude. When the addition of conductive filler is further increased beyond a specific value, the resistivity of the composite tends to be stable again, and further addition of filler materials cannot significantly improve the resistivity of the material. This relationship is called conductive percolation.

2.2. Introduction to the application of conductive composites

Conductive composite materials have low density, corrosion resistance and other characteristics, and conductive filler and polymer in conductive composite materials can be arbitrarily adjusted and selected, so conductive composite materials have obvious application elasticity, can be used in different fields of science and technology, such as batteries, electromagnetic shielding materials, light-emitting diodes and other fields [5]. Polymers in conductive composite materials, such as polyaniline, realize the oxidation-reduction reaction through the reversibility of doping and de-doping in the electrode reaction process of conductive polymer and complete the battery charging and discharging process. This principle could lead to conductive polymers being used in lithium-ion batteries. At the same time, the conductive polymer has the advantage of being anti-static so it can be used as an excellent electromagnetic shielding material in electronic products and medical devices. For instance, the screen saver and the electromagnetic shielding material in pacemakers. Conductive composite materials can be used in light-emitting diodes. The luminous active layer made of conductive composite materials has better luminous stability. The IBM research team uses polyaniline as the electrode isolation layer, which greatly prolongs the life of light-emitting devices.

3. Carbon nanomaterials

3.1. CNTs (multi-wall and single-wall)

CNTs, also known as buckytube, are unidimensional quantum materials with a special structure [6]. The carbon atoms in the CNTs are primarily hybridized sp2 forming a structure of spatial topology. Common

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methods for preparing CNTs consist of arc discharge approach, laser ablation strategy, chemical steam deposition, incandescent discharge and polymerization reaction synthesis method. CNTs are electrically conductive. Because the structure of CNTs is the same as the lamellar structure of graphite with exceptional electrical properties. CNTs showcase outstanding electrical conductivity, often as much as 10,000 times that of copper. However, CNTs are reported to be toxic to living organisms. CNTs are not pure carbon; nickel, chromium, and the other metals used to produce them are impurities. These residual metals and CNTs have the potential to slow growth and even kill certain species of aquatic life.

3.2. Graphene

There are many different methods for preparing graphene, two of which are mechanical stripping and chemical vapor deposition [7]. Some researchers use low-pressure vapor deposition (LPS) to generate graphene monolayers on the air surface. Further studies have shown that graphene structures can be scaled across metal steps, and continuous and micron-scale carbon monolayers are gradually formed on the air surface. Millimeter-scale single-crystal graphene was obtained by surface segregation. Some scholars have discovered centimeter-scale graphene and epitaxial growth on polycrystalline Ni film graphene. After a period of reaction, a few layers of graphene films over a large area will be formed on the metal surface after heating the Ni film surface with a thickness of 300 nm at 1000 °C and exposing it to the CH_4 atmosphere.

Graphene also has many magical effects [8]. For example, in recent years, young Chinese scientist Cao Yuan discovered the magic Angle effect of graphene. The magic angle twisted three-layer graphene shows superconductivity in the in-plane magnetic field of more than 10T, which greatly violates the Pauli limit (2~3 times) of traditional spin-singlet superconductors for an unpredicted strong spin-orbit coupling. This is an unexpected observation for the system. The breaking of the poly limit is observed throughout the superconducting phase, which indicates that it is independent of the possible pseudogap phase. Notably, reentry superconductivity has been observed in large magnetic fields.

3.3. Graphene oxide

GO is an oxide of graphene with color of brown and yellow [9]. After oxidation, its properties are more active than graphene due to the increase of oxygen-containing functional groups, which can improve its properties. GO can act like a surfactant at the interface and reduce the energy between the interfaces. Its hydrophilicity is widely recognized. Due to the addition of several oxygen-containing groups on the surface and edge, graphene oxide, a single-layer substance stripped from graphite oxide, can exist steadily in an aqueous solution and polar solvent. The graphite oxide still has graphene layers after oxidation, but each layer has many more oxygen functional groups added to it. Adding these oxygen functional groups significantly increases the complexity of the single graphene structure. Many scientists have attempted to provide a thorough and precise description of the structure of GO in light of the position of GO. According to the widely recognized structural model, carboxyl and carbonyl groups are introduced at the sheet's borders, whereas hydroxyl and epoxy groups are randomly distributed throughout the GO sheet. Current theoretical research demonstrates that the surface functional groups of GO are significantly correlated rather than randomly dispersed.

3.4. Activated carbon

Activated carbon is mainly made of wood chips, bituminous coal, fruit shell and other materials after carbonization and activation of the porous black material due to the preparation of diverse, complex materials made of activated carbon adsorption capacity [10]. The pore structure is also different. Activated carbon is mainly divided into charcoal as the main raw material and coal as the main raw material.

Charcoal is the main raw material of activated carbon, mainly wood and fruit shell. Wood chips can be used to produce powdered activated carbon because the wood itself has loose porous, fewer impurities and other characteristics, so made of activated carbon has excellent characteristics, such as hole volume, than coal activated carbon hole volume is larger. The activated carbon, made of coconut and a common fruit shell, has various characteristics. This is because the coconut shell is an excellent activated carbon material, coconut shell in the process of carbonization, the cell wall decomposes into the diameter of a micron hole, and the fiber structure of the coconut shell itself is not destroyed, so compared with wood chips to make activated carbon, activated carbon made of coconut shell has better strength. The activated carbon with coal as the main raw material is compared with the activated carbon mentioned above because the production process is the same, and the performance is ordinary.

Activated carbon is loose, porous, and has a large surface area, so it has good adsorption and conductivity, making activated carbon used in many scientific and technological fields, such as conductive materials, batteries, etc., as shown in Figure 1 [10]. Graphite microcrystals are composed of about three parallel planar graphite layers. At the same time, the graphite layers will change, such as peeling, erosion and dislocation, and the graphite microcrystals have different sizes, different shapes and irregular arrangements, thus forming many voids [6]. The higher the oxygen content of activated carbon, the more acidic it is. Activated carbon with acidic surface groups has cation exchange characteristics, while activated carbon with low oxygen content shows alkaline and anion exchange characteristics. Taking polyaniline, a polymer in conductive composite material, as an example, as a composite with activated carbon, aniline is synthesized under acidic conditions to obtain good conductivity of the material. Therefore, the increase of oxygen-containing functional groups is likely to improve the conductivity of the composite material.

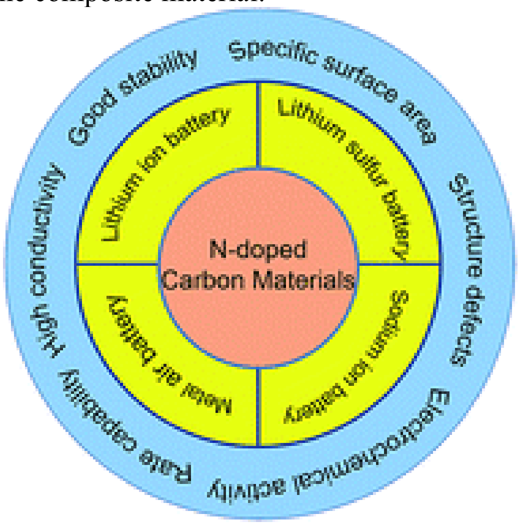

Figure 1. The properties and applications of N-doped carbon materials [10].

4. Application of carbon materials as conductive composites

Carbon materials can be used as one of the fillers' conductive composites because of their portability, environmental protection, low cost and good conductive properties [7]. Conducting polymers can be divided into the intrinsic type and compound type. The Intrinsic-type conductive polymer has poor conductive stability. The compound conductive polymer has a simple preparation method, excellent conductive and good stability, and is widely used in conductive composite materials. Conductive composite material filler mainly includes three categories of carbon, metal, and metal oxide. The conductive composite material with CNTs and polyurethane as the filler has the advantages of high elasticity, wear resistance and oil resistance of polyurethane and retains the advantages of CNTs. However, CNTs have a large aspect ratio, specific surface area and strong van der Waals force, which are easy to aggregate or form bundles, difficult to disperse evenly in polyurethane matrix, and poor compatibility between CNTs and polyurethane. If CNTs are not treated with polyurethane composite, it is not easy to give full play to the excellent performance of CNTs. Therefore, the modification should be done before combining the two.

The solution blending method is simple to prepare CNTs polyurethane conductive composites. The main steps are as follows: (1) CNTs are surface modified and dispersed in a suitable solvent to form a dispersion solution; (2) CNT dispersion is evenly mixed with polyurethane; (3) The solvent is removed at the set temperature to form composite materials.

The melt blending method is aimed at fused polyurethane. CNTs are dispersed in the polyurethane matrix by the shear force during the mixing process and then formed by extrusion, injection and molding. This preparation method is simple to operate and low-cost, so it can be large-scale production and is widely used in practice. Carbon materials are widely used in conductive composites. Due to the high conductivity, price and density of metal conductive fillers, adding 30~50 composite metal fillers are usually necessary to obtain high conductive properties. Such a large amount of addition will cause great damage to the mechanical properties of the matrix materials. Carbon materials can significantly solve the above problems. Carbon conductive fillers have the advantages that metal fillers do not have, such as rich sources, easy-to-form conductive networks, and not easy oxidation, so they are widely used in industrial production. Carbon-based conductive fillers commonly used to fill rubber are carbon black, graphite, carbon fiber, CNTs and graphene. Filling rubber with carbon-based conductive filler can not only improve the conductive property of rubber but also improve the aging resistance and physical properties of rubber. Graphene is an emerging carbon material. Carbon atoms are arranged in hexagonal shapes and connected. The structure enables it to have very highly stable components.

5. Conclusions

In conclusion, Biocompatibility and shape memory of conductive PU-CNT composites are gaining popularity as useful materials for implants, shape memory micromachines and biosensors. stretchable conductive nanocomposites are useful in high-performance, flexible, and stretchable electronic circuits flexible mechanical drive systems, such as artificial skin and moving parts. The application of carbon nanomaterials in the preparation of conductive composites can produce conductive composites with various special properties, especially in the aspects of reducing mass and improving conductivity. It is necessary to study it further, which will have great potential in future fields such as ultra-high voltage and ultra-long distance power transmission and high-temperature superconductivity.

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