

Double-walled carbon nanotube dispersion *via* surfactant substitution

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A new approach for the stabilisation of double-walled carbon nanotubes in aqueous media was developed. A low molecular weight surfactant was used in the first stage for the debundling of the nanotubes followed by substitution with a higher molecular weight surfactant or non-ionic surfactants. Dispersions were characterized by optical density measurements, SEM and DLS. The presence of remaining low molecular weight surfactant was investigated by FT-IR. Double walled carbon nanotube dispersions showed good dispersion stability and non-detectable amounts of the initial surfactant, which was completely removed. Such a method could be useful for preparation of stable aqueous dispersions of carbon nanotubes with low concentration of surfactants, which is especially important for toxicity studies.

1. Introduction

For many industrial applications a uniform and stable dispersion of particulate matter plays an important role. This requirement is especially critical when submicron or nanometer sized particles are involved, because the surface chemistry controls the dispersion state of such particles within a final product. It is extremely important to learn how to manipulate the surface properties in order to achieve a product with the desired properties.

The ability of surfactants to accumulate on surfaces or interfaces has been widely used to promote stable dispersions of solids in different media.^{1,2} Those amphiphilic molecules, *i.e.*, compounds having both polar and non-polar groups, adsorb at the interface between immiscible bulk phases, such as oil and water, air and water or particles and solution, and act to reduce the surface tension.

Carbon nanotubes (CNT) have a unique set of properties making them good candidates for a wide range of possible applications in suspensions and polymer-based solutions, melts and composites.³ Their outstanding characteristics include attractive mechanical properties, namely tensile strength and elastic modulus, and still remarkable flexibility, excellent thermal and electrical conductivities, low percolation thresholds (loading weight at which a sharp drop in resistivity occurs) and high aspect ratios (length to diameter ratio). Thus, they allow the preparation of composites with new or improved properties.⁴

The main challenge for integration of this unique nanomaterial is the preparation of uniform dispersions of CNT in the continuous phase. A major obstacle to this separation effort is the aggregation of nanotubes. The highly polarizable nanotubes readily form bundles (or ropes) with a van der Waals binding

energy of *ca.* 500eV per micrometer of tube-tube contact.⁵ This makes all attempts to separate them by size or type or to use them as individual macromolecular species difficult. Moreover, the electronic structure of an individual single-walled CNT (SWNT) can be disturbed because of bundling. Debundling these ropes to yield individual nanotubes is consequently non-trivial.

CNT can be dispersed in water when coated with adsorbed surfactants, preferentially with those having relatively high HLB (hydrophilic-lipophilic balance). This non-covalent method is straightforward and classically employed to disperse both organic and inorganic particles in aqueous solutions. The nature of the surfactant, its concentration, and type of interaction are known to play crucial roles in the phase behavior of classical colloids⁶ as well as CNT.⁷

Knowledge of the surface charge of carbon nanotubes in different media is absolutely essential for understanding the interaction (adsorption) mechanism with ionic surfactants, and to predict colloidal stability of CNT suspensions. While zeta-potential analysis of multi-walled CNT (MWNT) has shown that the tubes are negatively charged in water,⁸ some groups demonstrated insufficient debundling power of the anionic surfactant sodium dodecyl sulfate (SDS) due to charge repulsion.⁹ Among the ionic surfactants, SDS¹⁰ and dodecyl-benzene sodium sulfonate (NaDDBS)¹¹ were commonly used to decrease the CNT aggregative tendency in water. The benzene ring of the latter (π -stacking) was suggested to be one of the main reasons for the high dispersive efficiency of NaDDBS.¹²

Physical association of polymers with the surface of CNT was shown to enhance their dispersion in both water and organic solvents, and is another way for non-covalent CNT stabilization.¹³ Two mechanisms were suggested: "wrapping",¹⁴ which is believed to rely on specific interactions between a given polymer and the tubes; however, recent small-angle neutron scattering studies evidenced a non-wrapping conformation of polymers in CNT dispersions.¹⁵

Another kind of compounds which can be used for dispersion of CNT in water for specific biomedical application are carbohydrate derivatives, such as natural polysaccharides (gum arabic)

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Double Walled Carbon Nanotube Dispersion Via Surfactant

A. Paipetis, V. Kostopoulos



Double Walled Carbon Nanotube Dispersion Via Surfactant:

Solubilization and Dispersion of Carbon Nanotubes Oxana Vasilievna Kharissova, Boris Ildusovich

Kharisov, 2017-09-01 This book describes a series of contemporary techniques and their combinations used for CNTs solubilization from physical to chemical and biological applying inorganic and organic compounds as well as some metal complexes In some cases successive steps can be applied for instance the use of low and high weight surfactants or mineral acid treatment for creation of OH and COOH groups and their further interaction with organic molecules Each discussed method leads to an improvement of CNT solubility frequently a considerable one The formed dispersions can be stable for long periods of time from several weeks to some months and they sometimes even remain stable after centrifugation Several special studies have been carried out in the areas of influence of solvent and light on CNTs dispersibility combinations and abilities of surfactants CNT cytotoxicity etc Applications of solubilized CNTs are discussed in this book as well **Inorganic**

and Composite Fibers Boris Mahltig, Yordan Kyosev, 2018-10-18 Inorganic and Composite Fibers Production Properties and Applications provides a comprehensive review on the development production and application of modern inorganic and composite fibers Particular emphasis is placed on current production processes parameters and finishing and functionalization methods for improving their properties and the problems associated with the testing of fibers Fibers covered include carbon glass and basalt fibers metal fibers such as copper and steel fibers coated with silver or gold and nitinol In addition to pure inorganic fibers the book looks at organic fibers with a high level of inorganic content such as cellulosic fibers Including contributions from leading experts from universities research institutes and producing companies this book assists materials scientists and engineers in the composites automotive textile and medical industries to more efficiently and effectively select fibers for a range of different applications areas Presents a thorough introduction to inorganic fibers such as carbon fiber and nanotubes graphene glass fibers and many more including the fundamentals of production processing and finishing of each fiber type Includes coverage of a range of application areas of inorganic fibers to assist in product development Keeps researchers up to date by providing information on the latest developments in this field thus supporting further research *Carbon Nanotubes for Biomedical Applications* Rüdiger Klingeler, Robert B.

Sim, 2011-02-09 This book explores the potential of multi functional carbon nanotubes for biomedical applications It combines contributions from chemistry physics biology engineering and medicine The complete overview of the state of the art addresses different synthesis and biofunctionalisation routes and shows the structural and magnetic properties of nanotubes relevant to biomedical applications Particular emphasis is put on the interaction of carbon nanotubes with biological environments i e toxicity biocompatibility cellular uptake intracellular distribution interaction with the immune system and environmental impact The insertion of NMR active substances allows diagnostic usage as markers and sensors e g for imaging and contactless local temperature sensing The potential of nanotubes for therapeutic applications is highlighted by

studies on chemotherapeutic drug filling and release targeting and magnetic hyperthermia studies for anti cancer treatment at the cellular level *Single-Walled Carbon Nanotubes* Yan Li,Shigeo Maruyama,2019-05-16 The series Topics in Current Chemistry Collections presents critical reviews from the journal Topics in Current Chemistry organized in topical volumes The scope of coverage is all areas of chemical science including the interfaces with related disciplines such as biology medicine and materials science The goal of each thematic volume is to give the non specialist reader whether in academia or industry a comprehensive insight into an area where new research is emerging which is of interest to a larger scientific audience Each review within the volume critically surveys one aspect of that topic and places it within the context of the volume as a whole The most significant developments of the last 5 to 10 years are presented using selected examples to illustrate the principles discussed The coverage is not intended to be an exhaustive summary of the field or include large quantities of data but should rather be conceptual concentrating on the methodological thinking that will allow the non specialist reader to understand the information presented Contributions also offer an outlook on potential future developments in the field *Carbon Nanomaterials for Advanced Energy Systems* Wen Lu,Jong-Beom Baek,Liming Dai,2015-11-02 With the proliferation of electronic devices the world will need to double its energy supply by 2050 This book addresses this challenge and discusses synthesis and characterization of carbon nanomaterials for energy conversion and storage Addresses one of the leading challenges facing society today as we steer away from dwindling supplies of fossil fuels and a rising need for electric power due to the proliferation of electronic products Promotes the use of carbon nanomaterials for energy applications Systematic coverage synthesis characterization and a wide array of carbon nanomaterials are described Detailed descriptions of solar cells electrodes thermoelectrics supercapacitors and lithium ion based storage Discusses special architecture required for energy storage including hydrogen methane etc *Carbon Nanotubes Mediated Bioactive Delivery* Neelesh Kumar Mehra,N.K. Jain,2025-08-12 Carbon nanotubes CNTs have emerged as novel carbon based nanomaterials with unique physicochemical properties for pharmaceutical and biomedical applications This book provides the fundamental concept basic physicochemical properties functionalization method of synthesis applications and regulatory considerations of CNTs The primary objective of the editors and authors is to exhaustively cover the fundamentals of carbon nanomaterials carbon nanotubes functionalization and chemistries involved drug delivery aspects and applications along with their regulatory aspects *Aerospace Materials Handbook* Sam Zhang,Dongliang Zhao,2012-11-19 Whether an airplane or a space shuttle a flying machine requires advanced materials to provide a strong lightweight body and a powerful engine that functions at high temperature The Aerospace Materials Handbook examines these materials covering traditional superalloys as well as more recently developed light alloys Capturing state of the art developments in materials research for aeronautical and aerospace applications this book provides a timely reference for both newcomers and veteran researchers in the field The chapters address developments in bulk materials coatings traditional materials and new materials Beginning with an

overview of superalloys including nickel nickel iron and cobalt based superalloys the text covers machining laser cladding and alloying corrosion performance high temperature oxidation thermal spraying and nanostructured coatings It also includes four categories of composites used in aerospace metal matrix polymer carbon nanotube reinforced polymer and self healing composites The text describes preparation processing and fatigue of lightweight magnesium alloys as well as an exciting new class of materials aerogels This book brings readers to the cutting edge of research in materials for aerospace and aeronautics It provides an entry point into this field and presents details to stimulate future research This unique up to date resource offers knowledge to enable practitioners to develop faster more efficient and more reliable air and spacecraft

Principles of Regenerative Medicine Anthony Atala,Robert Lanza,James A. Thomson,Robert Nerem,2010-12-16

Virtually any disease that results from malfunctioning damaged or failing tissues may be potentially cured through regenerative medicine therapies by either regenerating the damaged tissues in vivo or by growing the tissues and organs in vitro and implanting them into the patient Principles of Regenerative Medicine discusses the latest advances in technology and medicine for replacing tissues and organs damaged by disease and of developing therapies for previously untreatable conditions such as diabetes heart disease liver disease and renal failure Key for all researchers and institutions in Stem Cell Biology Bioengineering and Developmental Biology The first of its kind to offer an advanced understanding of the latest technologies in regenerative medicine New discoveries from leading researchers on restoration of diseased tissues and organs

Carbon Nanotubes Giorgia Pastorin,2019-05-08 This book represents a critical evaluation of the most recent discoveries about carbon nanotubes and includes a cautious description of their impact on personal health and environmental pollution It also offers an overview of the main research groups around the world which have been focusing their efforts on the exploitation of this intriguing material with the purpose of inspiring young scientists to follow their pathway

Carbon Nanotube Enhanced Aerospace Composite Materials A. Paipetis,V. Kostopoulos,2012-09-14 The well documented increase in the use of high performance composites as structural materials in aerospace components is continuously raising the demands in terms of dynamic performance structural integrity reliable life monitoring systems and adaptive actuating abilities Current technologies address the above issues separately material property tailoring and custom design practices aim to the enhancement of dynamic and damage tolerance characteristics whereas life monitoring and actuation is performed with embedded sensors that may be detrimental to the structural integrity of the component This publication explores the unique properties of carbon nanotubes CNT as an additive in the matrix of Fibre Reinforced Plastics FRP for producing structural composites with improved mechanical performance as well as sensing actuating capabilities The successful combination of the CNT properties and existing sensing actuating technologies leads to the realization of a multifunctional FRP structure The current volume presents the state of the art research in this field The contributions cover all the aspects of the novel composite systems i e modeling from nano to macro scale enhancement of structural efficiency

dispersion and manufacturing integral health monitoring abilities Raman monitoring as well as the capabilities that ordered carbon nanotube arrays offer in terms of sensing and or actuating in aerospace composites **Carbon Nanotube-Polymer Composites** Brian P. Grady, 2011-07-08 The accessible compendium of polymers in carbon nanotubes CNTs Carbon nanotubes CNTs extremely thin tubes only a few nanometers in diameter but able to attain lengths thousands of times greater are prime candidates for use in the development of polymer composite materials Bringing together thousands of disparate research works Carbon Nanotube Polymer Composites Manufacture Properties and Applications covers CNT polymers from synthesis to potential applications presenting the basic science and engineering of this dynamic and complex area in an accessible readable way Designed to be of use to polymer scientists engineers chemists physicists and materials scientists the book covers carbon nanotube fundamentals to help polymer experts understand CNTs and polymer physics to help those in the CNT field making it an invaluable resource for anyone working with CNT polymer composites Detailed chapters describe the mechanical rheological electrical and thermal properties of carbon nanotube polymer composites Including a glossary that defines key terms Carbon Nanotube Polymer Composites is essential reading for anyone looking to gain a fundamental understanding of CNTs and polymers as well as potential and current applications including electronics shielding and transparent electrodes flame retardants and electromechanics sensors and actuators and their challenges

Carbon Nanotube-Polymer Nanocomposites Srikanta Moharana, Lipeeka Rout, Suresh Sagadevan, 2024-09-13 This book presents the latest advancements in various synthetic techniques properties characterization and efficient applications of CNT polymer nanocomposites The preparation properties characterization and applications of these technologically intriguing new materials are discussed in detail The book covers a wide range of topics from the fundamentals of carbon nanotubes their reinforced polymer nanocomposites and their applications in various fields including energy storage 3D printing electronics aerospace and coatings and environmental and bio medical bioengineering It is a good resource for students material scientists and professionals interested in the synthesis properties characteristics and cutting edge applications of carbon nanotubes polymer nanocomposites *Handbook of Carbon Nanotubes* Jiji Abraham, Sabu Thomas, Nandakumar Kalarikkal, 2022-11-16 This Handbook covers the fundamentals of carbon nanotubes CNT their composites with different polymeric materials both natural and synthetic and their potential advanced applications Three different parts dedicated to each of these aspects are provided with chapters written by worldwide experts in the field It provides in depth information about this material serving as a reference book for a broad range of scientists industrial practitioners graduate and undergraduate students and other professionals in the fields of polymer science and engineering materials science surface science bioengineering and chemical engineering Part 1 comprises 22 chapters covering early stages of the development of CNT synthesis techniques growth mechanism the physics and chemistry of CNT various innovative characterization techniques the need of functionalization and different types of functionalization methods as well

as the different properties of CNT A full chapter is devoted to theory and simulation aspects Moreover it pursues a significant amount of work on life cycle analysis of CNT and toxicity aspects Part 2 covers CNT based polymer nanocomposites in approximately 23 chapters It starts with a short introduction about polymer nanocomposites with special emphasis on CNT based polymer nanocomposites different manufacturing techniques as well as critical issues concerning CNT based polymer nanocomposites The text deeply reviews various classes of polymers like thermoset elastomer latex amorphous thermoplastic crystalline thermoplastic and polymer fibers used to prepare CNT based polymer composites It provides detailed awareness about the characterization of polymer composites The morphological rheological mechanical viscoelastic thermal electrical electromagnetic shielding properties are discussed in detail A chapter dedicated to the simulation and multiscale modelling of polymer nanocomposites is an additional attraction of this part of the Handbook Part 3 covers various potential applications of CNT in approximately 27 chapters It focuses on individual applications of CNT including mechanical applications energy conversion and storage applications fuel cells and water splitting solar cells and photovoltaics sensing applications nanofluidics nanoelectronics and microelectronic devices nano optics nanophotonics and nano optoelectronics non linear optical applications piezo electric applications agriculture applications biomedical applications thermal materials environmental remediation applications anti microbial and antibacterial properties and other miscellaneous applications and multi functional applications of CNT based polymer nanocomposites One chapter is fully focussed on carbon nanotube research developments published papers and patents Risks associated with carbon nanotubes and competitive analysis of carbon nanotubes with other carbon allotropes are also addressed in this Handbook

Electrochemistry of Carbon

Electrodes Richard C. Alkire, Philip N. Bartlett, Jacek Lipkowski, 2016-03-31 The book sets the standard on carbon materials for electrode design For the first time the leading experts in this field summarize the preparation techniques and specific characteristics together with established and potential applications of the different types of carbon based electrodes An introductory chapter on the properties of carbon together with chapters on the electrochemical characteristics and properties of the different modifications of carbon such as carbon nanotubes graphene carbon fiber diamond or highly ordered pyrolytic graphite provide the reader with the basics on this fascinating and ubiquitous electrode material Cutting edge technologies such as carbon electrodes in efficient supercapacitors Li ion batteries and fuel cells or electrodes prepared by screen printing are discussed giving a complete but concise overview about the topic The clearly structured book helps newcomers to grasp easily the principles of carbon based electrodes while researchers in fundamental and applied electrochemistry will find new ideas for further research on related key technologies

Photophysics of Carbon Nanotubes

Interfaced with Organic and Inorganic Materials Igor A. Levitsky, William B. Euler, Victor A. Karachevtsev, 2012-12-22

Photophysics of Carbon Nanotubes Interfaced with Organic and Inorganic Materials describes physical optical and spectroscopic properties of the emerging class of nanocomposites formed from carbon nanotubes CNTs interfacing with

organic and inorganic materials The three main chapters detail novel trends in photophysics related to the interaction of light with various carbon nanotube composites from relatively simple CNT small molecule assemblies to complex hybrids such as CNT Si and CNT DNA nanostructures The latest experimental results are followed up with detailed discussions and scientific and technological perspectives to provide a through coverage of major topics including Light harvesting energy conversion photoinduced charge separation and transport in CNT based nanohybrids CNT polymer composites exhibiting photoactuation and Optical spectroscopy and structure of CNT DNA complexes Including original data and a short review of recent research Photophysics of Carbon Nanotubes Interfaced with Organic and Inorganic Materials makes this emerging field of photophysics and its applications available to academics and professionals working with carbon nanotube composites in fundamental and applied fields

Handbook of Thermoset Plastics Hanna Dodiuk, 2021-10-25 Handbook of Thermoset Plastics Fourth Edition provides complete coverage of the chemical processes manufacturing techniques and design properties of each polymer along with its applications This new edition has been expanded to include the latest developments in the field with new chapters on radiation curing biological adhesives vitrimers and 3D printing This detailed handbook considers the practical implications of using thermoset plastics and the relationships between processing properties and applications as well as analyzing the strengths and weakness of different methods and applications The aim of the book is to help the reader to make the right decision and take the correct action on the basis of informed analysis avoiding the pitfalls the authors experience has uncovered In industry the book supports engineers scientists manufacturers and R D professionals working with plastics The information included will also be of interest to researchers and advanced students in plastics engineering polymer chemistry adhesives and coatings Offers a systematic approach guiding the reader through chemistry processing methods properties and applications of thermosetting polymers Includes thorough updates that discuss current practice and the new developments on biopolymers nanotechnology 3D printing radiation curing and biological adhesives Uses case studies to demonstrate how particular properties make different polymers suitable for different applications Covers end use and safety considerations

Thermal Energy Storage Hafiz Muhammad Ali, Furqan Jamil, Hamza Babar, 2021-04-12 This book covers various aspects of thermal energy storage It looks at storage methods for thermal energy and reviews the various materials that store thermal energy and goes on to propose advanced materials that store energy better than conventional materials The book also presents various thermophysical properties of advanced materials and the role of thermal energy storage in different applications such as buildings solar energy seawater desalination and cooling devices The advanced energy storage materials have massive impact on heat transfer as compared to conventional energy storage materials A concise discussion regarding current status leading groups journals and the countries working on advanced energy storage materials has also been provided This book is useful to researchers professionals and policymakers alike

Carbon Nanotube Based Composites Antonio Pantano, 2012-09-28 Carbon nanotubes

CNTs have amazing properties and a key way to take advantage of this is by incorporating nanotubes into a matrix to build composite materials. The best candidates for this task are undoubtedly polymers. Almost every characteristic of a polymer can be significantly enhanced by adding carbon nanotubes and as a result new potential applications of carbon nanotube enhanced polymer composites are discovered every day. However, before carbon nanotube enhanced polymer composites become commonplace, there are some tough challenges that need to be overcome. This book reviews the status of worldwide research in both single-walled and multi-walled carbon nanotube based composites. It serves as a practical guide on carbon nanotube based composites and a reference to students and researchers from the academia and industry.

Aligned Carbon Nanotubes Zhifeng Ren, Yucheng Lan, Yang Wang, 2012-09-05. This book gives a survey of the physics and fabrication of carbon nanotubes and their applications in optics, electronics, chemistry, and biotechnology. It focuses on the structural characterization of various carbon nanotubes, fabrication of vertically or parallel aligned carbon nanotubes on substrates or in composites, physical properties for their alignment, and applications of aligned carbon nanotubes in field emission, optical antennas, light transmission, solar cells, chemical devices, bio devices, and many others. Major fabrication methods are illustrated in detail, particularly the most widely used PECVD growth technique, on which various device integration schemes are based, followed by applications such as electrical interconnects, nanodiodes, optical antennas, and nanocoax solar cells, whereas current limitations and challenges are also discussed to lay the foundation for future developments.

Advances in Nanostructured Composites Mahmood Aliofkhazraei, 2019-04-30. Composites and nanocomposites are used in cases where long durability and strength of components are required, i.e. where high stress levels, erosion processes, and multiphase environments are present, including the parts under collision and impact, the parts under rotating motion, and erosion like excavation drills in oil and gas wells. The first volume of this book aims to provide a guide for fabrication of new nanocomposites mainly based on carbon nanotubes and graphene. The main topics of this volume are: Application of Nano powders for Formation of Metal Matrix of Composites, Conjugated Polymer Nanocomposites, Biopolymer Nanocomposites, Dental Nanocomposites, Graphene based Nanocomposites for Electrochemical Energy Storage, Polymer Filler Composites for Optical Diffuse Reflectors, Synthesis and Applications of LDH Based Nanocomposites, Rubber CNT Nanocomposites, Nanocomposite Fibers with Carbon Nanotubes, Fabrications of Graphene Based Nanocomposites for Electrochemical Sensing of Drug Molecules, Recent Advances in Graphene Metal Oxide Based Nanocomposites.

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