

# Dielectric and microwave properties of carbon nanotubes/carbon black filled natural rubber composites

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Natural rubber (NR) based nanocomposites containing a constant amount (50 phr) of standard furnace carbon black and carbon nanotube (CNT) at a concentration from 1 to 5 phr have been prepared. Their dielectric (dielectric permittivity and dielectric loss) and microwave properties (coefficients of absorption and reflection of the electromagnetic waves and electromagnetic interference shielding effectiveness) have been investigated in the 1–12 GHz frequency range. The results achieved allow recommending CNTs as second filler for NR based composites to afford specific absorbing properties.

**Keywords:** Natural rubber composites, Carbon nanotubes, Dielectric and microwave properties

## Introduction

Since the documented discovery of carbon nanotubes (CNTs) in 1991 by Iijima<sup>1</sup> and the realisation of their unique<sup>2</sup> physical properties, including mechanical, thermal and electrical, many investigators have endeavoured to produce advanced CNT composite materials that exhibit one or more of these properties. For example, CNT are quite effective as a conductive filler of polymers, compared to traditional carbon black micro-particles, primarily due to their high aspect ratios. Recently, the electrical percolation threshold has been reported to be at 0.0025 wt-% of CNT and conductivity at  $2.5 \text{ S m}^{-1}$  at 1.0 wt-% of CNT in epoxy matrices.<sup>3</sup>

Owing to their fibrous shape with extremely large aspect ratio, CNT may, at a very low concentration, yield composites of low resistivity, high permittivity and frequency dispersion.<sup>4</sup> It is well known that the nanosized particles usually exhibit properties different from those of micro-sized particles of the same composition, which is the primary reason for the great attention currently paid to the radio and microwave frequency performance of CNT composites. A number of novel CNT features have been reported in the literature.<sup>5–11</sup> These results demonstrate

the possibility to design CNT composites with electrical/dielectric properties, which are more diverse than those obtainable with other carbon fillers.

There are numerous investigations on nanocomposites based on elastomeric matrices and CNTs as filler, although the researchers' attention has been directed mainly to the reinforcement of polymer matrices. The influence of this unique filler upon the dielectric and microwave properties of the elastomeric composites has been scarcely studied. Lately, there have been articles suggesting possible applications of such nanocomposites in microwave absorbers for solving problems of electromagnetic interference (EMI) and electromagnetic compatibility.<sup>4,12–20</sup> The polymer matrices used in these cases are usually epoxy resin, acrylonitrile-butadiene rubber, styrene-butadiene rubber, silicone rubber and polyurethane rubber. Only in the last years have appeared reports on the investigations on natural rubber (NR) based nanocomposites filled with CNTs.<sup>21–24</sup>

The price of CNTs is still significantly higher than that of standard furnace carbon black. In this context, the aim of this study is to determine whether the addition of small quantities (1–5 phr) of CNT in addition to a standard significantly greater than the amount of active furnace carbon black (50 phr) can be used as a way to modify and improve the dielectric (dielectric permittivity, dielectric loss) and microwave properties [coefficient of reflection, coefficient of attenuation and EMI shielding effectiveness (SE)] of NR based composites in the high frequency range (1–12 GHz). Data for such a study on the reported combination of fillers have not been found in the literature.

## Experimental

### Characterisation of carbon nanofillers used

Multiwalled CNTs as produced by Hayzen Engineering Co. (Ankara, Turkey) were used in our investigation.

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# **Dielectric And Microwave Properties Of Natural Rubber**

**Chin Hua Chia, Chin Han Chan, Sabu  
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## **Dielectric And Microwave Properties Of Natural Rubber:**

**Flexible and Stretchable Electronic Composites** Deepalekshmi Ponnammam, Kishor Kumar Sadasivuni, Chaoying Wan, Sabu Thomas, Mariam Al-Ali AlMa'adeed, 2015-10-16 This book is the first comprehensive collection of electronic aspects of different kinds of elastomer composites including combinations of synthetic natural and thermoplastic elastomers with different conducting fillers like metal nanoparticles carbon nanotubes or graphenes and many more It covers elastomer composites which are useful in electronic applications including chemical and physical as well as material science aspects The presented elastomer composites have great potential for solving emerging new material application requirements for example as flexible and wearable electronics The book is structured and organized by the rubber elastomer type each chapter describes a different elastomer matrix and its composites While introducing to important fundamentals it is application oriented discussing the current issues and challenges in the field of elastomer composites This book will thus appeal to researchers and scientists to engineers and technologists but also to graduate students working on elastomer composites or on electronics engineering with the composites providing the readers with a sound introduction to the field and solutions to both fundamental and applied problems

**Progress in Rubber Nanocomposites** Sabu Thomas, Hanna J. Maria, 2016-10-27 Progress in Rubber Nanocomposites provides an up to date review on the latest advances and developments in the field of rubber nanocomposites It is intended to serve as a one stop reference resource to showcase important research accomplishments in the area of rubber nanocomposites with particular emphasis on the use of nanofillers Chapters discuss major progress in the field and provide scope for further developments that will have an impact in the industrial research area Global leaders and researchers from industry academia government and private research institutions contribute valuable information A one stop reference relating to the processing and characterization of rubber nanocomposites Presents the morphological thermal and mechanical properties that are discussed in detail Contains key highlights in the form of dedicated chapters on interphase characterization applications and computer simulation

**Functional Polymeric Composites** Chin Hua Chia, Chin Han Chan, Sabu Thomas, 2017-11-23 This new work Functional Polymeric Composites Macro to Nanoscales focuses on new challenges findings opportunities and applications in the area of polymer composites The chapters written prominent researchers from academia industry and research institutes from around the world present contemporary research and developments on advanced polymeric materials including polymer blends polymer electrolytes bio based polymer polymer nanocomposites etc Several chapters also cover the applications of the polymeric systems in current industry development and synthesis and characterization of the products

**Hybrid Polymer Composite Materials** Vijay Kumar Thakur, Manju Kumari Thakur, Asokan Pappu, 2017-06-03 Hybrid Polymer Composite Materials Applications provides a clear understanding of the present state of the art and the growing utility of hybrid polymer composite materials It includes contributions from world renowned experts and discusses the combination of

different kinds of materials procured from diverse resources In addition this volume from the four volume series provides deep insights on the potential of hybrid polymer composite materials for advanced applications Provides a clear understanding of the present state of the art and the growing utility of hybrid polymer composite materials Includes contributions from world renowned experts and discusses the combination of different kinds of materials procured from diverse resources Discusses their synthesis chemistry processing fundamental properties and applications Provides insights on the potential of hybrid polymer composite materials for advanced applications Graphene Science Handbook, Six-Volume Set Mahmood Aliofkhazraei,Nasar Ali,William I. Milne,Cengiz S. Ozkan,Stanislaw Mitura,Juana L. Gervasoni,2016-04-26

Graphene is the strongest material ever studied and can be an efficient substitute for silicon This six volume handbook focuses on fabrication methods nanostructure and atomic arrangement electrical and optical properties mechanical and chemical properties size dependent properties and applications and industrialization There is no other major reference work of this scope on the topic of graphene which is one of the most researched materials of the twenty first century The set includes contributions from top researchers in the field and a foreword written by two Nobel laureates in physics *Graphene Science Handbook* Mahmood Aliofkhazraei,Nasar Ali,William I. Milne,Cengiz S. Ozkan,Stanislaw Mitura,Juana L. Gervasoni,2016-04-27

Discover the Unique Electron Transport Properties of GrapheneThe Graphene Science Handbook is a six volume set that describes graphene s special structural electrical and chemical properties The book considers how these properties can be used in different applications including the development of batteries fuel cells photovoltaic cells and s **Proceedings of the 7th International Conference on Electrical, Control and Computer Engineering-Volume 1** Zainah Md. Zain,Norizam Sulaiman,Mahfuzah Mustafa,Mohammed Nazmus Shakib,Waheb A. Jabbar,2024-10-02

This book presents the proceedings of the 7th International Conference on Electrical Control and Computer Engineering InECCE 2023 held in Kuala Lumpur Malaysia on 22 August 2023 The topics covered are sustainable energy power electronics and drives and power engineering including distributed renewable generation power system optimization artificial computational intelligence smart grid power system protection and machine learning energy management and conservation The book showcases some of the latest technologies and applications developed to solve local energy and power problems in order to ensure continuity reliability and security of electricity for future generations It also links topics covered the Sustainable Development Goals SDGs areas outlined by the United Nation for global sustainability The book appeals to professionals scientists and researchers with experience in industry The book represents Volume 1 for this conference proceedings which consist of a 2 volume book series **Electromagnetic Aquametry** Klaus Kupfer,2006-01-27

Mformation about a material can be gathered from its interaction with electromagnetic waves The information may be stored in the amplitude the phase the polarisation the angular distribution of energy transportation or the spectral characteristics When re trieved from the wave certain material properties may thus be determined indirectly

Compared on the one hand to direct material analysis an indirect method requires calibration and is prone to interference from undesired sources On the other hand however it permits the determination of features inaccessible by direct methods such as non destructive material interrogation high measurement speed or deep penetration depth However being a physical method the use of electromagnetic waves is still handicapped by the lack of acceptance by many chemists who are used to applying direct approaches Historically the first application of electromagnetic wave interaction with mat ter involved measurement of amplitude changes at a single frequency caused by material properties and it is still used today by some systems This approach was soon supplemented by single frequency phase measurements in order to avoid distortions through amplitude instabilities or parasitic reflections Such single pa rameter measurements of course require dependence only on one variable in the measured process and sufficient stability of all other ancillary conditions If that is not the case the single parameter measurement fails

**Conducting Polymer-Based Nanocomposites** Ayesha Kausar,2021-04-22

Conducting Polymer Based Nanocomposites Fundamentals and Applications delivers an up to date overview on cutting edge advancements in the field of nanocomposites derived from conjugated polymeric matrices Design of conducting polymers and resultant nanocomposites has instigated significant addition in the field of modern nanoscience and technology Recently conducting polymer based nanocomposites have attracted considerable academic and industrial research interest The conductivity and physical properties of conjugated polymers have shown dramatic improvement with nanofiller addition Appropriate fabrication strategies and the choice of a nanoreinforcement along with a conducting matrix may lead to enhanced physicochemical features and material performance Substantial electrical conductivity optical features thermal stability thermal conductivity mechanical strength and other physical properties of the conducting polymer based nanocomposites have led to high performance materials and high tech devices and applications This book begins with a widespread impression of state of the art knowledge in indispensable features and processing of conducting polymer based nanocomposites It then discusses essential categories of conducting polymer based nanocomposites such as polyaniline polypyrrole polythiophene and derived nanomaterials Subsequent sections of this book are related to the potential impact of conducting polymer based nanocomposites in various technical fields Significant application areas have been identified for anti corrosion EMI shielding sensing and energy device relevance Finally the book covers predictable challenges and future opportunities in the field of conjugated nanocomposites Integrates the fundamentals of conducting polymers and a range of multifunctional applications Describes categories of essential conducting polymer based nanocomposites for polyaniline polypyrrole polythiophene and derivative materials Assimilates the significance of multifunctional nanostructured materials of nanocomposite nanofibers Portrays current and future demanding technological applications of conjugated polymer based nanocomposites including anti corrosion coatings EMI shielding sensors and energy production and storage devices

Applied Chemistry and Chemical Engineering, Volume 2 A. K. Haghi,Lionello Pogliani,Devrim Balkose,Omari V.

Mukbaniani, Andrew G. Mercader, 2017-12-22 This book covers many important aspects of applied chemistry and chemical engineering focusing on three main aspects principles methodology and evaluation methods It presents a selection of chapters on recent developments of theoretical mathematical and computational conceptions as well as chapters on modeling and simulation of specific research themes covering applied chemistry and chemical engineering This book attempts to bridge the gap between classical analysis and modern applications Covering a selection of topics within the field of applied chemistry and chemical engineering the book is divided into several parts polymer chemistry and technology bioorganic and biological chemistry nanoscale technology selected topics This book is the second of the two volume series Applied Chemistry and Chemical Engineering The first volume is Volume 1 Mathematical and Analytical Techniques **Microwave Materials and Applications, 2 Volume Set** Mailadil T. Sebastian, Rick Ubic, Heli Jantunen, 2017-05-08 Die j ngsten Fortschritte im Bereich der drahtlosen Telekommunikation und dem Internet der Dinge sorgen bei drahtlosen Systemen beim Satellitenfernsehen und bei intelligenten Transportsystemen der 5 Generation f r eine h here Nachfrage nach dielektrischen Materialien und modernen Fertigungstechniken Diese Materialien bieten ausgezeichnete elektrische dielektrische und thermische Eigenschaften und verf gen ber enormes Potenzial vor allem bei der drahtlosen Kommunikation bei flexibler Elektronik und gedruckter Elektronik Microwave Materials and Applications erl utert die herk mmlichen Methoden zur Messung der dielektrischen Eigenschaften im Mikrowellenbereich die verschiedenen Ans tze zur L sung von Problemen der Materialchemie und von Kristallstrukturen in den Bereichen Doping Substitution und Aufbau von Verbundwerkstoffen Besonderer Schwerpunkt liegt auf Verarbeitungstechniken Einfl ssen der Morphologie und der Anwendung von Materialien in der Mikrowellentechnik Gleichzeitig werden viele der j ngsten Forschungserkenntnisse bei Mikrowellen Dielektrika und Anwendungen zusammengefasst Die verschiedenen Kapitel untersuchen Oxidkeramiken f r dielektrische Resonatoren und Substrate HTCC LTCC und ULTCC B nder f r Substrate Polymer Keramik Verbundstoffe f r Leiterplatten Elastomer Keramik Verbundstoffe f r flexible Elektronik dielektrische Tinten Materialien f r die EMV Abschirmung Mikrowellen Ferrite Ein umfassender Anhang pr sentiert die grundlegenden Eigenschaften von mehr als 4000 verlustarmen dielektrischen Keramiken deren Zusammensetzung kristalline Struktur und dielektrischen Eigenschaften f r Mikrowellenanwendungen Microwave Materials and Applications wirft einen Blick auf s mtliche Aspekte von Mikrowellenmaterialien und anwendungen ein n tzliches Handbuch f r Wissenschaftler Unternehmen Ingenieure und Studenten die sich mit heutigen und neuen Anwendungen in den Bereichen drahtlose Kommunikation und Unterhaltungselektronik besch ftigen **Continuous Vulcanisation of Elastomer Profiles** A. Hill, 1997 This report provides a review of the principles of continuous vulcanisation together with details of the systems which are available commercially References are provided throughout drawing together the scientific literature and material published by the equipment suppliers An indexed section containing several hundred key references and abstracts completes the report enabling the reader to locate additional data on specific

aspects of the process      Rubber Nano Blends Gordana Markovic, Visakh P. M., 2016-11-25 This book summarizes the preparation characterization and applications of rubber based nano blends Rubbers from natural and synthetic polymers and their blends are discussed in the individual chapters including nitrile polyurethane chlorosulphonated polybutadiene styrene butadiene polychloroprene rubbers In each chapter contributors from academia and industry describe the preparation and characterization of the rubber blends Therefore a variety of characterization methods like tensile testing differential scanning calorimetry dynamical mechanical analysis thermogravimetric analysis electron microscopy scattering and diffraction techniques and rheology measurements are utilized The authors evaluate the properties of the different materials and discuss numerous fields of application ranging from biomedicine packaging coatings and automobile to aerospace

Zeitschrift für physikalische Chemie ,1973      Materials for Potential EMI Shielding Applications Kuruvilla Joseph, Runcy Wilson, George Gejo, 2019-11-01 Materials for Potential EMI Shielding Applications Processing Properties and Current Trends extensively and comprehensively reviews materials for EMI shielding applications ranging from the principles to possible applications and various types of shielding materials The book provides a thorough introduction to electromagnetic interference its effect on both the environment and other electronic items various materials that are used for electromagnetic interference shielding applications and its properties It explains the mechanism behind EMI shielding the methods by which EMI SE of a given material is estimated and the different fabrication methods currently employed for fabricating EMI shielding materials Final sections focus on the theoretical background of EMI shielding and shielding mechanisms This theoretical background is extended to the physics of EMI shielding wherein the physics behind mechanism of shielding is explained Focuses on the different types of available EMI shielding their applications processing characterization and the mechanism behind their shielding Discusses how to incorporate EMI shielding with low cost low density and high strength Provides an understanding and clarifies both elementary and practical problems relating to EMI shielding materials

Lightweight Polymer Composite Structures Sanjay Mavinkere Rangappa, Jyotishkumar Parameswaranpillai, Suchart Siengchin, Lothar Kroll, 2020-09-01 This book provides a comprehensive account of developments in the area of lightweight polymer composites It encompasses design and manufacturing methods for the lightweight polymer structures various techniques and a broad spectrum of applications The book highlights fundamental research in lightweight polymer structures and integrates various aspects from synthesis to applications of these materials Features Serves as a one stop reference with contributions from leading researchers from industry academy government and private research institutions across the globe Explores all important aspects of lightweight polymer composite structures Offers an update of concepts advancements challenges and application of lightweight structures Current status trends future directions and opportunities are discussed making it friendly for both new and experienced researchers      Thermal Microwave Radiation C Mätzler, 2006-05-19 Combines theoretical concepts with experimental results on thermal microwave radiation to increase the understanding of

the complex nature of terrestrial media Emphasising on radiative transfer models this book covers the terrestrial aspects from clear to cloudy atmosphere precipitation ocean and land surfaces vegetation snow and ice **Indian Journal of Pure & Applied Physics** ,2008-07 **Natural Rubber Materials** Sabu Thomas,Chin Han Chan,Laly A Pothan,Jithin Joy,Hanna Maria,2013-12-05 A comprehensive two volume set covering the synthesis characterization and applications of natural rubber based blends interpenetrating polymer networks composites and nanocomposites *Fundamental and Applied Nano-Electromagnetics II* Antonio Maffucci,Sergey A. Maksimenko,2019-06-14 The increasing prevalence of nanotechnologies has led to the birth of nanoelectromagnetics a novel applied science related to the interaction of electromagnetic radiation with quantum mechanical low dimensional systems This book provides an overview of the latest advances in nanoelectromagnetics and presents contributions from an interdisciplinary community of scientists and technologists involved in this research topic The aspects covered here range from the synthesis of nanostructures and nanocomposites to their characterization and from the design of devices and systems to their fabrication The book also focuses on the novel frontier of terahertz technology which has been expanded by the impressive strides made in nanotechnology and presents a comprehensive overview of the synthesis of various nanostructured materials study of their electrical and optical properties use of nano sized elements and nanostructures as building blocks for devices design and fabrication of nanotechnology devices operating in the THz IR and optical range The book introduces the reader to materials like nanocomposites graphene nanoplatelets carbon nanotubes metal nanotubes and silicon nanostructures to devices like photonic crystals microcavities antennas and interconnects and to applications like sensing and imaging with a special emphasis on the THz frequency range



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