CNTs/Polymer composite coated cotton fabrics for EMI Shielding applications – A short view of contemporary review

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Abstract

Electromagnetic interference (EMI), is a new type of pollution brought on by the widespread use of intelligent, compact, and highly integrated electronics. Therefore, it is thought that it is crucial to control the destructive effects of electromagnetic radiation by using flexible and light shielding materials. Due to their conductivity, mechanical elasticity, facile coating capability, etc., CNTs-based cotton fabrics have been demonstrated to be effective for shielding applications. These fabrics have a wide range of uses, from defensive (against microwaves and antibacterial) to self-propelled, for everyday clothing. This study covers the synthesis methodology and mechanisms in depth, moving from the fundamentals of EMI shielding through the most recent studies on CNTs-textiles. Based on these changes, the review's objective is to disseminate some important, recent evidence about CNTs-cotton fabrics, multifunctional uses, and developments in CNTs-textiles in this area.

Keywords: Cotton fabrics; EMI Shielding, CNTs

Introduction

Due to their remarkable physical and chemical properties and as well as their potential applications in electronics, energy storage, aerospace, medicine, and materials science, carbon nanotubes (CNTs) have captured the attention of both the scientific community and various industries. The large-scale synthesis, cost-effectiveness, and potential negative effects on human health and the environment present additional obstacles to the broad use of CNTs-based devices [1-5].

One of the oldest and most often used materials in human history is textile (woven, non-woven), more specifically cotton fabrics (natural fibers). It is a crucial component of our daily life because it gives us clothing, bedding, and a variety of other goods that improve our comfort and wellbeing. In comparison to some synthetic fibers, cotton fabrics are an environmentally friendly option because of its many advantageous qualities, including softness and comfort, absorbency, breathability, versatility, durability, and ease of dyeing. Cotton is also a renewable and biodegradable resource. Cotton is still an essential component of the worldwide textile industry today. From ordinary apparel to high-end fashion, home textiles, medical supplies, and industrial components, cotton is used to make a wide variety of goods [6, 7].

Generally, Textile (natural fabric or man-made fabrics) industries focused to develop their innovative technology are implemented on the fabrics for social demands. Cotton fabrics are frequently treated with polymers to improve their characteristics, add additional benefits, and increase their effectiveness in a variety of uses. It is possible to apply polymers to cotton fabrics using a variety of techniques, including coating, impregnation, and finishing. PTFE (poly tetrafluoroethylene) and PVDF (polyvinylidene fluoride) are two examples of fluoropolymers that are frequently used on cotton fabrics. Polyacrylates, polyurethanes, and silicones are other common fluoropolymers. On the fabric surface, these polymers produce a robust and long-lasting protective coating. It is significant to take into account that the precise qualities and functions needed for the cotton fabric impact the choice of polymers and the application technique. More sustainable and environmentally friendly polymer compositions are also being worked on for textile applications [8-18].

CNTs have been incorporated into polymer matrices through a number of attempts in order to create CNTs/polymer composites for EMI shielding [13-17]. It has gained significant attention in materials science due to their enhanced mechanical, electrical, thermal, and other functional properties. The combination of CNTs with polymers results in a synergistic effect, where the unique properties of both components complement each other. Apart from the CNTs lot of functional materials are used on cotton fabrics for EMI shielding applications [19-23].

As far as we are aware, there is no published review of CNTs-polymer composites on cotton fabrics for EMI shielding applications in a very recent year of 2022 to till data. This review discusses the recent progress on CNTs-cotton fabrics for EMI shielding applications, including their synthesis of CNTs, and mechanisms of EMI. Moreover, challenges and future prospects are also discussed, which will help the researchers and technologists who work in this area to improve their knowledge. Here, we studied some of the very recent research articles of textile fabrics using CNTs /polymers composites for some notable applications of EMI.

The VNAS scattering parameter was calibrated before the measurements. The samples that must be measured were cut into a rectangle shape with a size of 10.6 mm (length) × 4.3 mm (width) to match the waveguide holders. The incident electromagnetic wave power was 0 dBm, corresponding to 1 mW. The EMI parameters SE total, SE reflection and SE absorption (SE_T, SE_R, and SE_A, respectively) were calculated from S_{11} and S_{21}.

Absorption shielding effectiveness and reflection shielding effectiveness

In order to clarify the main shielding mechanism of CNTs-coated cotton fabrics, the absorption and reflection shielding effectiveness, absorptivity and reflectivity of CNTs-coated cotton fabric were further studied [31]. Absorptivity (A, the percentage of absorption to incidence of EM weave), reflectivity (R, the percentage of reflection to incidence of EM weave), absorption shielding effectiveness (SE_A) and reflection shielding effectiveness (SE_R) were calculated according to the scattering parameters S_{11} and S_{21} measured by a vector network analyser, the computational formula is as follows [18, 22]:

$$S_{21}=10\log T$$

$$\%T=10^{S_{21}/10} \times 100$$

$$S_{11}=10\log R$$

$$\%R=10^{S_{11}/10} \times 100$$

According to the principle of conservation of energy, the value of absorptivity can be calculated as

$$\%A=100-(\%R - \%T)$$

In addition, the electromagnetic wave that can enter the inside of the shielding material needs to be subtracted from the reflected portion, which is 1-R, hence the effective absorption rate A_{eff} is:

$$A_{eff} =1-R-T/1-R$$

Based on the above analysis, SE_R and SE_A can be expressed as

$$SE_R=-10 \log (1-R)$$

$$SE_A=-10 \log (1-A_{eff})=-10 \log (T/1-R)$$

Here, reflection shielding effectiveness (SE_R), absorption shielding Effectiveness (SE_A)

2. Synthesis of CNTs

Carbon nanotubes (CNTs) are cylinder-shaped materials made by packing carbon atoms into a hexagonal lattice during the manufacturing process. The diameter, number of walls, and chirality (the configuration of carbon atoms in the tube's lattice) of CNTs can all affect their qualities. Single-walled carbon nanotubes (SWCNTs), which consist of a seamless tube, and multi-walled carbon nanotubes (MWCNTs), which consist of nested tubes, are the two main forms of CNTs. There are numerous ways to make it, with Arc Discharge, Chemical Vapor Deposition (CVD), Vapor phase growth, Flame synthesis method, Laser Ablation, and nebulized spray pyrolysis method [24-29]

Commercially available CNTs: Recently, top manufacturers like Jiangsu Cnano Technology Co., Nanocyl SA, Carbon Solutions, Inc., and Cheap Tubes, Inc. have provided CNTs to researchers with affordable price [30].

2.1 Functionalization of CNTs

CNTs involves modifying their sidewall functionalized with various chemical functionalization [31] by covalent (alkyl fluoride, amino, hydroxyl group, oxygenated functional group (HNO_3, H_2SO_4, $KMnO_4$)), non-covalent (aromatic component, Conjugated polymers, Surfactant) and encapsulation approaches or molecules to tailor their properties and improve their compatibility with polymer matrices. Functionalized CNTs offer better dispersion, adhesion, and interaction with polymers, leading to enhanced performance in composite materials. The functionalization procedure can vary depending on the desired application and the chemical groups used [32].

2.2 Composites of CNTs / Polymer Processing

It is essential to note that in order to obtain the necessary features and structures, both the polymerization and the CNTs synthesis procedures can be complicated and necessitate careful control of the reaction conditions. Surface of Functionalized CNTs have dispersing with long term stability to polymer matrices by high shear force due to the aggregates. Some of the important processing techniques have been successfully adopted for mixing of CNTs with polymer matrices like Solution processing, Melt Processing, In-situ Polymerization, wet spinning and so on which is for synthesis of CNTs-based polymer nanocomposites [33-38]. Additionally, improvements in research and technology retain these processes better, allowing the creation of polymers and CNTs with enhanced characteristics and applications.

2.3 Polymer/CNTs composites coated on cotton fabrics

There exist multiple techniques to coat cotton fabrics with polymer composites. The coating on the fabrics using polymer over the surface of fabrics followed by drying and curing. There are some types of coating that can be applied in the liquid form on the substrate of the fabrics like Dip and dry coating, micro dissolution process, in-situ polymerization method and pad-dry cure method [39-43].

2.4 CNTs/Polymer Composite on cotton fabrics for EMI shielding

In the textile industry, CNTs offer several promising applications, enhancing the performance and functionality of cotton fabrics and natural fibers. Here are a few noteworthy uses of CNTs in cotton textiles, particularly for EMI shielding in a recent years [44-48]:

CNTs possess excellent electromagnetic interference (EMI) shielding properties. Incorporating CNTs into textiles can create EMI shielding fabrics, which are valuable for applications in electronics, aerospace, and defense industries to protect sensitive equipment from electromagnetic interference.

3. Some of the very recent research articles studied the CNTs on cotton fabrics (CF).

Wang et al. [44] worked on Multilayered cotton fabric (CF/Liquid Metals (LM)/CNT) was successfully fabricated by multi-layer spraying and mechanical compression. The double face-sprayed CF/LM/CNT exhibited a highly conductive behavior with an electrical resistance of 0.07 Ω, and outstanding electro-magnetic shielding capability of about 85 dB (which outperform those of most reported EMI shielding materials) over the X band.

Arunkumar et al. [45] in their work developed CF with MWCNTs coating (CMC) through a dip and dry process. The author was studied transmission, reflection, and absorption properties for EMI shielding. The author was reported the significant increase of 98.9% of EMI shielding for the highest MWCNTs weight percentage (22.23 wt%) was attributed due to the well-interconnected network of MWCNTs on cotton fabrics.

Zhao Y et al. [46] fabricated a multifunctional EMI shielding composite fabric by in-situ polymerization of polypyrrole (PPy) hydrogel/MWCNT/cotton with Joule heating performances. The resultant of this studies exhibits a high EMI-SE of 48 dB within a large frequency range (8.2–12.4 GHz).The author conclude that the design type of multifunctional EMI shielding composite fabric with achieved high-efficiency electrophotothermal effect functions for wearable smart garments.

The recent trend of multifunctional CF with flame retardancy, external force sensing, super hydrophobicity, washability, human motion-sensing abilities and EMI shielding performance by Chenlu Xie et al. [47] The author discovered a conductive CF with cross-linked wrinkled microstructure is fabricated via a facile spray-coating approach, by CNTs as skeletons and Ti3C2Tx Mxene nanosheets as stacking layers. The resultant fabric exhibits high EMI shielding effectiveness (EMI SE) of 46.05 dB in the X-band at a thickness of only 138 μm.

A recent study by Horita Y et al. [48] fabricated electrically conductive CF can be fabricated with a low sheet resistance using a simple polydopamine (PDA) and Single-wall carbon nanotubes (SWCNTs) through a dip-and-dry method for flexible device applications. Here, the authors compared two types of SWCNT inks, with and without dispersant, and conducted heat-treatment to optimize the fabric's electrical resistance. The fabricated fabrics showed a low sheet resistance and effective EMI shielding properties. The results showed that the DMF-SWCNT-PDA cotton fabrics had a low sheet resistance of 9 ± 2 Ω/sq. In addition to that, EMI Shielding Efficiency (SE) and return loss were measured in the two frequency ranges (one sample (6 × 3 cm^2) for 4–6 GHz and another sample (3 × 3 cm^2) for 8–12 GHz) using wave-guides with VNA and simulated by the frequency 3D electromagnetic field analysis software (Ansys HFSS). The measured SE from VNA was about – 30 dB for the two frequency ranges i.e 4-6 GHz and 8-12 GHz. The study highlights the potential of SWCNT inks and PDA-assisted fabrication methods for creating high-conductive cotton fabrics for various applications.

4. Conclusion

This review discusses some of the most recent CNTs/cotton fabric-based research. Additionally, the fundamental characteristics of CNTs inserted into polymers for EMI shielding in the textile industries were briefly explored. As was already noted, polymer nanocomposites have applications across a wide range of industries. In this study, the impact of CNTs and their composites on textiles has been restricted of publications, particularly in 2022 and the present. Furthermore, continuous studies and advancements in the sector have an impact on the use of CNTs in textiles in the future.

5. Challenges and Future outlook

CNTs can be expensive to create, and their high price may prevent their widespread use in textiles, particularly for items targeted towards consumers. It has an ability to agglomerate, which results in non-uniform characteristics and possible flaws in the fabric, making it difficult to achieve uniform CNTs dispersion in textile substrates. It integration must be possible without affecting the characteristics of the textile when used with current methods of spinning, weaving, and dyeing. The demands of the textile industry are satisfied and scalable manufacturing of high-quality CNTs are required. Safe handling and disposal of CNTs have guaranteed the possible health and environmental implications must be thoroughly investigated and handled. Textiles containing CNTs additions should be strong enough to endure numerous washings without noticeably degrading.

Recently, many studies might result in more affordable and scalable CNTs synthesis techniques, opening up the material for textile applications. Advances in nanotechnology and materials science may result in better dispersion methods that resolve the problems with CNTs aggregation in textiles. The surface functionalization of CNTs can improve their characteristics and increase their compatibility with textile matrices, resulting in more efficient integration. CNTs and other nanomaterials, such Metal oxides, Metals, Carbon based materials like Graphene, Graphene oxide, can be combined to produce hybrid materials with improved textile functions. It integration can aid in the creation of smart textiles that have sophisticated features like electrical sensing and energy storage. As part of a smart textile, CNTs-integrated textiles have the potential to revolutionize various industries, including fashion, sports, healthcare, and electronics. Efforts to develop sustainable and eco-friendly CNTs production methods and

Creating clear regulatory standards for the safe use and removal of CNTs in textiles helps inspire trust among stakeholders, including producers and customers.

Conflict of Interest

There are no disclosed conflicts of interest for the authors.

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