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Textile applications of carbon nano tube

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Abstract

One of the major components of nanotechnology is Carbon nanotube (CNT) that can have a length to- diameter ratio more than 1,000,000. They are used in several fields in material science, due to their exceptional electrical, mechanical, and thermal properties, which are anisotropic. Different techniques have been developed to produce CNT. They have good potential for applications in various technological areas such as nano electronic, biotechnology, material science, polymer, composite, and textile industries. In this paper, recent researches on application of CNT in textile industry are reviewed. Treatment of textiles with CNT leads to the production of a wide variety of conductive textiles with different electrical properties. The wear performances of fabrics apply with CNT to open the potentiality of producing composite materials for conventional and innovative applications, ranging from conventional apparel and sportswear to protective clothing, heating equipment, automotive textiles, building covering, geo-textiles, biomedical textiles, etc.

Key words : Carbon nanotube; textile; smart; nano.

1 Introduction

Elemental carbon can form different structures in the *sp2* hybridization. The chemical bonding of nanotubes is composed entirely of *sp*2 bonds, similar to those of graphite. These bonds are stronger than the *sp*3 bonds and provide nanotubes with their unique strength. Apart from the well-known graphite, carbon can build closed and open cages with honeycomb atomic arrangement. The first such structure to be discovered was the C60 molecule. Although various carbon cages were studied, it was only in 1991, when Iijima observed for the first time tubular carbon structures. Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. As can be seen in Figure 1, nanotubes are classified as single-walled nanotubes (SWNT) and multi-walled nanotubes (MWNT). Single-walled nanotubes (SWNT) consist of a single graphite sheet seamlessly wrapped into a cylindrical tube. Most SWNTs have a diameter of about 1 nanometer but can be more often longer. The structure of a SWNT can be imagined by wrapping a one-atom-thick layer of graphite called grapheme into a seamless cylinder. The nanotubes consisted of up to several tens of graphitic shells called multi-walled carbon nanotubes (MWNT) with adjacent shell with high length/diameter ratio.

Two structural models of MWNT are Parchment model and Russian Doll model. In Parchment model, same as a rolled up scroll of paper sheet, a single graphene is wrapped around itself many times. But, if a CNT contains another nanotube inside it and the outer nanotube has a greater diameter than thinner nanotube, it is called the Russian Doll model [1-4].

2 Methods of manufacturing

A number of methods are available for manufacture of carbon nano tubes, which include methods such as arc discharge, laser ablation, high-pressure carbon monoxide disproportionation, and chemical vapor deposition (CVD) are being developed for production of CNTs but some can be found more in several reviews and reports. Most of these processes take place in a vacuum or with process gases. CVD growth of CNTs can occur in vacuum or at atmospheric pressure. Large quantities of nanotubes can be synthesized by these methods [5].

3 Properties

CNTs have unique electrical properties, heat conduction efficiency, stability and resilience and extraordinary strength. CNT structure has an effect on electrical properties of nanotubes.

Nanotubes have ability to be superconducting at low temperatures. Cause of the carbon–carbon sp2 bonding in CNT, they have high stiffness and axial strength and nanotubes are the stiffest known fiber, with a 1.4 TPa Young's modulus. CNTs have an expected elongation to failure of 20–30%, which combined with the stiffness and their tensile strength is more than 100 GPa. CNTs have incredible mechanical properties. They are the fastest known oscillators (>50 GHz) and are highly suited as building blocks for molecular electronics. CNT thermal properties are directly related to their unique structure and small size and they are ideal materials for thermal management studying. All nanotubes are good thermal conductors along the tube (ballistic conduction), but they are good insulators lateral to the tube axis [6].

4 General areas of applications

Carbon nanotubes have amazing structural, mechanical, and electrical properties and can be applicable in many fields and different industries, such as: medicine, manufacturing,

Nano technology, electronics, construction, polymer and textile. CNTs are applicable in energy storage and energy conversion devices, high-strength composites, hydrogen storage media, actuators, nanoprobes and sensors, electronic devices, and catalysis [7,8]. It has been aimed to provide an updated vision of the latest applications of CNT in fabric and textile industry.

5 Textile applications

Carbon nanostructures such as carbon nanotubes have wide range of potential applications and attracted great interest due to their unique anisotropic properties. Extraordinary properties of CNT have consistently attracted massive research interests [9-11]. There is a great deal of interest and activity in the present day to find applications for carbon nanotubes. SWCNTs have similar electrical conductivity as copper and similar thermal conductivity as diamond [12]. The composite fibers using CNT have potential applications in different industries [13]. CNT can be applied to the fabric by spray-coating, exhaustion, or simply dipping the textile into a CNT solution [14,15]. Also, by different fabrication processes such as wet spinning, carpet spinning, and aerogel-spun methods, CNTs have been assembled into macroscopic yarns or fibers [16]. CNT could cover a wide range of textile functions which is reviewed here

Conductive textiles

Materials that only consist of carbon atoms such as graphene, carbon black, and carbon nanotubes can have a wide range of conductivities, from the insulator diamond to conductors. Purity of the carbon compounds is an important factor for conductivity level [17]. To produce electrically conductive fibers, yarns, or fabrics, several methods can be used. Also different electrically conductive materials such as metal powders, graphite, carbon black, carbon nanotubes or intrinsically conductive polymers like polyaniline, thiophene and polypyrrole can be used [18]. For fabrication of intelligent clothes which are applicable in military, work wear, sportswear, portable power, foldable displays and healthcare, integration of electronic elements with conventional textiles is important and essential. Recently, carbon nanotubes because of their high surface area, light weight, excellent electric, and mechanical properties have been applied as the electronic element to make wearable electronic textiles [19]. Many researchers worked on the electrical conductivity of fibers and fabrics using carbon nanotubes, the results of conductive textile using CNT are reported and will be explained in the following. Conductive wool fabrics were prepared by Nafeie et al. in 2016. Different concentrations of MWCNT and carboxylated multi-wall carbon nanotube (CMWCNT) in presence of citric acid as a cross-linking agent and sodium hypophosphite as a catalyst were used. Different pretreatment methods such as oxidation by potassium permanganate, enzyme treatment with protease, and nanoTiO2 finishing have been studied. Anionic and cationic surfactants namely sodium dodecyl sulfate (SDS) and cetyltrimethyl ammonium bromide (CTAB) were also used to provide the best conditions for dispersing the nanotubes.

They concluded that, CTAB was more effective for dispersing MWCNT in water. MWCNT-treated sample indicated 10 times higher conductivity than MWCNT due to interactions between the carboxyl groups of CMWCNT and functional groups of wool. Wool sample pretreated with protease and treated with 5 g/L CMWCNT regarded as the optimum sample with the highest electrical conductivity of 2 × 10−3 S/cm [20]. In 2016, PET fabrics were modified by coating with MWCNT.

The nanotubes were deposited with the padding method on fibers surface from water suspension. Treated materials were flexible and easy to shape and also the conductivity of network was durable. In the other research, polyethylene imine was used to pretreating the cotton yarn to enhance the affinity of CNT for the yarn. Cause of density variation of SWCNT, obtained yarn can be used as chemiresistors, which demonstrate electrical response to ammonia gas at room temperature. Also, the functionalized yarn can be used to make wearable sensors [21]. The conductive properties of Polyester/Cotton woven fabric with a spatial network of carbon nanotubes formed on its surface has been studied. The multi-wall carbon nanotubes with a diameter of 9.5 nm, a length of 1.5 µm, purity of 90% and a specific surface of 250–300 m2/g was used. The conductivity of the PET/CO woven fabric depends on the quantity of the carbon nanotubes deposited on the fiber surface. They concluded that, obtained electro-conductive and hydrophobic composite fabrics can be used in various industrial fields Tae Won Lee, Han, et al., in 2016 produced a series of cellulose- based composite fibers reinforced with MWCNT containing multiple hydrogen bonding moiety via wet-spinning process using organic solvent system of dimethyl acetamide and lithium chloride. With the increment of the MWCNT containing multiple hydrogen bonding content from 0.5 wt% to 30.0 wt%, electrical conductivity of the MWCNT containing multiple hydrogen bonding /cellulose composite fibers increased considerably from ~10−8 to ~100 S/cm. Also, the electrical percolation threshold was evaluated to be formed at ~0.52 wt % MWCNT containing multiple hydrogen bonding. The cellulose composite fiber containing 30.0 wt% MWCNT containing multiple hydrogen bonding, which has high electrical conductivity of 2.7 S/cm and tensile strength of ~156 MPa can be applied for electrically conductive wires and electric heating elements in smart textiles [23].

Continuous CNT fibers were synthesized with a horizontal CVD reactor at 1100–1200 °C using the floating-catalyst method. It was reported that, after being infiltrated with epoxy, the resulting cross-linked CNT ribbons exhibited impressive improvements of an increase in strength by 13.5 times and an increase in stiffness by more than 63 times. Also, electrical conductivity reached up to 12,000 S/cm [24].

In the other research, electro spinning method for largescale production of CNTs based composite films can be used. Carboxylated multi-walled carbon nanotubes (MWCNTs–
COOH)/ poly(vinyl alcohol) (PVA) nanofiber mats were produced. The composite film with MWCNTs-COOH fraction 8.76 wt% exhibits electrical conductivity of 1.8 × 10−4 S/cm, while maintaining 166.98 MPa tensile strength and 61% optical transmittance [25].

A melt extrusion method was used by Lin et al. in 2016 to coat polyester yarns with polypropylene and multi-walled carbon nanotubes (MWCNT). They concluded that, 8 wt%
MWCNT result in electrical conductivity of 0.8862 S/cm. Processing technologies can prepare PP/MWCNTs-coated PET conductive yarns that have satisfactory electrical conductivity, and can be used in functional woven and knitted fabrics, wearable electronics and battery-heated armor [26]. From the results, it can be concluded that, in the most researches related to electrical conductivity of fabrics, MWCNT were used. By these methods, conductive yarns and fabrics that have satisfactory electrical conductivity were prepared which can be used in electric and electronic equipment industry [27-38]. Also weight concentration of used CNT is a very important factor. As a result, CNT–treated materials have good potential for smart textiles.

Supercapacitors

In the last recent years, researchers are interested in producing flexible, lightweight, and implantable energy storage systems to address the energy-supply problem of wearable electronics. We ar able electronics ranging from high-performance sports wears, military garment devices, and personal health monitors to wearable computers. It is extremely urgent to develop mini-sized and lightweight energy storage system for wearable electronics.

Electrochemical capacitors which are called super capacitors can store energy using either ion adsorption/desorption at the electrode/electrolyte interface or surface/near-surface reversible reactions. Super capacitor has been regarded as one of the most promising alternatives in comparison to other energy storage systems cause of faster charge–discharge rates, higher power density, super-long cycle life, pollution-free operation, and better reversibility.

Textile super capacitors are typical sorts of examples of these kinds of novel energy storage devices and were designed by either directly converting the textile and fabrics into electrically conductive and electrochemically active fabric via carbonization or by coating the fibers with functional thin film layers like carbon nanotubes [39-41]. Ultrathin layer of acid-treated MWCNT were wrapped on cotton textiles for electro deposition of MnO2nanoflakes by Jiang et al. in 2015. Such conductive textiles show outstanding flexibility and strong adhesion between the CNT and the textiles of interest. Super capacitors made from these conductive textiles show high specific and capacity retention of 94.7% can be maintained at 2000 continuous charge discharge cycles [42].

In the other research, 3D porous ternary composite electrodes have been prepared, with electrodepositing MnO2 and poly (3, 4-ethylenedioxythiophene) (PEDOT) on carbon fabric-aligned carbon nanotube (CF-ACNT) hybrids for the super-capacitors [43]. The ternary composites with substantially high mass loading exhibit an excellent rate capability and cycling stability, retaining over 95% of its initial charge after 1000 cycles. They concluded that excellent electrochemical properties were attributed to the nanostructure and synergetic effect of each component. CF-ACNT acts as a 3D framework with an interconnected porous structure. MnO2 provides high charge storage ability and PEDOT serves as a conductive bridge. Zhang et al. 2014 in developed a lightweight and highly conductive membrane substrate. The substrate was based on the CNT, ethylene vinyl acetate copolymer (EVA), and lens wiping paper. They have demonstrated its implementation as high-performance mechanical support for MnO2 in super capacitors.

The 45 s-MnO2/ EVA/40 wt% CNT electrode exhibited a high capacitance (0.126 F cm−2 at 0.5 mA cm−2) with excellent flexibility and stability (85% of its initial capacitance retained after 800 bending cycles) and also achieved a high energy density of 9.4 Wh kg−1 at 6780 W kg−1.They suggested that, the EVA/40 wt% CNT paper hold great promise for low-cost, lightweight, and high-performance flexible energy storage applications [44]. These textiles electrode essentially maintained its whole structural integrity. It can be concluded that hybrid flexible electrodes and conductive textile are an effective strategy toward high-energy super capacitors and also are applicable in flexible energy storage devices.

Sensors

CNTs are attractive nano materials for wearable sensor fabrication cause of their unique properties such as ultralight weight, high aspect ratio, high electrical conductivity, high mechanical strength, and high thermal conductivity. CNT sensors are functional, flexible and ideal for energy saving. CNT wearable sensors are applicable for sensing in medical equipment, environmental sensor, and motion detection [45,46]. CNT nominating as gas sensor cause of their unique properties and it applied alone and/or when it blended or fabricated with other materials [47].

Flexible wearable sensor has been manufactured which doped with multi-walled carbon nanotubes. These kind of sensors can monitor medical physiology, movement, and environment [48,49]. Mentioned sensor was flexible, highly durable, lightweight, and conformable. It has been reported that, electrospun polyvinylidene fluoride/MWCNTs nonwoven fabrics exhibited better electrical and mechanical properties in the aligned direction. They reported that wearable sensing device generated current of ~30 nAp-p (Imax = ~20 nA) and an average voltage of ~200 mVp-p (Vmax = ~150 mV) while receiving a 6 Hz mechanical vibration with a maximum tensile strain of 0.06% and without noticeable degradation, the electrical outputs are relatively stable. Also, to detect viruses, CNT-based sensors can be used [50].

EMI shielding

In a polymer nanocomposite, the EMI shielding effectiveness depends on concentration of conductive filler, electrical conductivity, and formation of conductive networks [51]. CNT was verified to be useful for EMI shielding and EM wave absorption performances. The interfacial contact electrical resistance between CNT could restrain the increase of electrical conductivity. To achieve flexible electromagnetic shielding materials with thin thickness and low electromagnetic wave reflection, pyrolytic carbon (PyC) and carbon nanotube were *in situ* formed on the surface of SiC fibers through chemical vapor deposition (CVD) and catalytic chemical vapor deposition (CCVD). Flexible CNT/SiC fabrics with thin thickness could increase the absorption of EM wave and keep the reflected EM wave. With the formation of CNT, the EMI SE of SiC fabrics increased from 7.1 to 15.5 dB and reflection loss (SER) increased from 1.8 dB to 5.4 dB at10 GHz. The prepared CNT/SiCf has an excellent EMI shielding effect with highly absorbing performance [52].

In the other research, electromagnetic shielding (EM) fabrics have been produced by knife-over-roll coating and using combinations of CNT, metal nanoparticles and conductive polymer. Silver nanoparticles, Nickel-coated carbon fiber filler, MWCNT and Polypyrrole nanoparticles (Ppy) were used as conductive materials. The tested EM range was 200–1000 MHz and obtained coating thickness was 100–200 µm. By this method, fabrics with EM shielding of 95–99.99% (15–40 dB) has been prepared (Bonaldi, Siores, & Shah, 2014) [53].
In other work in 2007, a nanocomposite with superior microstructure and improved EMI shielding characteristic has been manufactured using carbon nanofibers and a small quantity of CNT within the polystyrene matrix [54]. Mentioned nanocomposite is used as an effective EMI shielding material owing to its low cost, high shielding effectiveness, easy processability and light weight and it provided 12.9 dB at 10 wt% of filler content for solution-spray processable polystyrene nano composite at 12.4–18 GHz range.

Fire retardant textiles

Carbon nanotubes are flame resistant and thermally anisotropic. CNT can conduct heat along the axis of an individual tube. They are relatively insulating across the tube's diameter. Anisotropic behavior of CNT can transfer the heat through a layer of aligned carbon nanotubes in textile and can be partially redirected to a cold reservoir and protect the wearer and fire fighters from exhaustion and heat stress (Sullivan et al., 2015) [55]. Low loading rate (<3 wt %) for improving the flame retardancy of a large range of polymers has been reported [56-61]. Carbon nanotube-embedded textiles like cotton fabric are more flame retardant and thermally stable than raw textiles [62]. Lack of compatibility between carbon nanotubes and textiles has limited their application in the textile industry. MWCNT were stabilized on a cotton surface using vinyl phosphonic acid monomer as a cross-linking agent and benzophenone as a catalyst to fabricate a flame retardant coating on the cotton through UV irradiation [63]. They reported that, direct utilization and stabilization of CNT resulted in achievement of high-efficient flame retardant finishing of cotton fabrics and improvement of its thermal properties.
In 2011, MWCNT were incorporated into polyurethane fibers as flame-retardant using electro-spinning method by Im et al. To improve the dispersivity of the MWCNT in the polyurethane fibers, surfaces of the MWCNT were modified using oxyfluorination. To prevent the decomposition of polyurethane by oxygen radicals, MWCNT promoted the formation of a charred layer as a protective film [64]. Carbon nanotubes can be used for improving the flame retardancy of textiles and composites [65,66].

Crease resistant fabrics

Crease resistant finishing of fabrics is a necessary treatment. By penetrating carbon nanotubes and carboxylated CNTs into cellulosic chains of cotton fabrics, crease resistance and strength of cotton textiles are improved [67,68]. Alimohammadi et al. in 2011 claimed that for crease resistant test, CNT-embedded cotton pieces were folded for about five minutes under a compression force and then recovery angle was measured. Seven textile samples were prepared: raw cotton sample, a cotton sample treated with a solution including the cross-linking agent and the catalyst SHP, and CNT-embedded cotton with different CNT concentrations. The recovery angle of raw cotton was 109.9°, for Cross-linked Cotton was140.4° and for 100, 250, 500, 1000 and 1500 ppm CNT-embedded cotton was 93.4°, 118.2°, 124.8°, 129.2° and145.6° respectively. They concluded that the cross-linked cotton has better crease resistant properties than CNT-embedded cotton at CNT concentrations lower than 1500 ppm. But by increasing the concentration of CNT to more than 250 ppm, the crease resistant properties of the CNT-embedded cotton are better than raw cotton

Reinforcements

By two methods, CNT is introduced into fiber-reinforced polymer composites. By matrix modification, which CNTs mix entirely throughout the matrix or interface modification, in which CNT attached onto reinforcing fibers [69]. CNT is effective filler that can improve the polymer properties.Wang et al. in 2013 fabricated carbon fabric/carboxylic acid-functionalized MWCNT-modified epoxy composites and concluded that by adding 0.025 wt% of CNT, the Tg of the hybrid composites improved up to 29 °C. By adding more CNTs in epoxy, re-agglomeration and filtering by carbon fabric are observed and uniform distribution in hybrid composites is reduced [70].
For ballistic protection, a new kind of polyurethane/p-aramid multi-axial fabric composites with improved dynamic mechanical properties was studied [71]. To enhance the properties of the composite polyurethane/p-aramid multi-axial fabrics, oxidized CNT and modified SiO2 nanoparticles were added. They found that, oxidized CNT/modified SiO2 hybrid nanoparticles had a great influence in improvement of the thermo-mechanical properties of composite. Also polyvinyl butyral/ oxidized-MWCNT/modified SiO2 film yielded 141% improvement in indentation hardness together with117% improvement in reduced elastic modulus.

In the other research, CNT nano-reinforced laminated composite was designed for improving the matrix-dominated properties of fiber-reinforced polymeric composites [72]. For growing the CNT on the surfaces of carbon fibers, CVD method and Nickel catalyst particles were used. They concluded that, CNT increases the effective diameter of the fiber, also larger interface area for the polymeric matrix is provided to wet the fiber. By adding 10% CNT volume content, elastic modulus of the CNT nano-reinforced laminated composite in the transverse direction to the fiber increases several fold. Effects of thermal treatments on structures and properties of aerogel-spun CNT fibers were studied [73]. Mechanical properties of the CNT fibers improved due to the enhanced crystallinity and interfacial interaction between CNT and aerogel by thermal treatments. In the other point of view, Zhu et al. in 2016 reported that, wear rate decreased 77% by adding 3 wt% MWCNT into epoxy composite when compared to pure epoxy [74]. Better wear resistance of the MWCNT/epoxy composite can be due to the high mechanical property and dispersion quality of CNT in epoxy matrix [75]. Due to the reinforcement by the CNT, the strength and stiffness increase.

Water/Oil repellence textiles

Owing to the CNT nanostructures, the aligned carbon nanotubes have superhydrophobic properties [76-80]. By CNT treatment on the surface of cotton fabrics, the surface form like an artificial lotus leaf structure and the surface of the treated cotton will be roughed. It has been reported that after CNT coating on the surface of cotton fabric, super hydrophobic properties appear with water contact angles larger than 15° [81].

UV protection textiles

Inorganic UV blockers are chemically stable and nontoxic Nanoscale semiconductor oxides efficiently absorb and scatter UV radiation. Scattering depends on the size of the nanoparticles and the wavelength [82]. Cotton fibers have been functionalized with CNT using surface coating method. They reported that, CNT network armor has been fabricated on the surface of cotton fibers and cotton fabrics show very good UV protection using 0.25% of CNT. CNT can improve the UV-blocking properties of polymer materials. Disadvantage of using CNT in textile is the coloration effect. Cotton fabrics will become black after the treatment. For reducing the coloration effect of the CNT on textiles, it is suggested to combine the CNT with other UV-blocking additives. UV absorption properties of single-wall and multi-wall CNT were studied and results were compared with the chemical UV absorber (Ciba Fast W) and mineral UV absorbers (ZnO and TiO2). CNTs, especially the SWCNT, have the specific absorption value at the UV region of the electromagnetic spectrum like common UV absorbers. SWCNT and MWCNT can be introduced in UV protection finishing for textiles [83,84].

Biological applications such as artificial muscle or scaffold

CNT in polymer matrix have been studied for biomedical applications in recent years. Carbon nanotube (specially MWNT) can be used for biomedical scaffolds. Cause of honeycomb-like structure, they have very good potential for scaffolds in tissue engineering [85]. Lima et al. have designed electrolyte-free muscles with guest-filled twist-spun CNT yarns [86]. They used dispersed CNT and nanotube sheets for electrically heating thermally actuating materials to provide cantilever deflections and demonstrated large-stroke, high-power, and high-work-capacity yarn muscles that provide millions of cycles and avoid the need for electrolyte or special packaging. Reversible actuation was powered by chemical absorption and desorption or photonically and electrically. It has been reported that designed muscle spins a rotor at an average 11,500 revolutions/minute or delivers 3% tensile contraction at 1200 cycles/minute [87].

Polymer/carbon nanotube fibers can be produced by solution (wet, dry, dry-jet or gel spinning) or melt spinning. Also, spun fibers using electro-spinning and different kind of CNT such as SWCNT, double-wall CNT, MWCNT, or vapor grown carbon nano fibers can be used. Less than 10 wt% carbon nanotubes can be used in composite fibers. Low-voltage actuators can be produced using CNT with the improvement in electrochemical and electrical properties. In the other point of view, shape memory polymers can be used widely in many areas such as textiles and may have good shape fixity but do not have enough elasticity and water vapor permeability. The conductive fillers like CNT can improve the thermal conductivity of shape memory polymers which contribute to a fast response. Miaud et al. studied about fibers which contain a large fraction of CNT embedded in polyvinyl alcohol (PVA) and achieved the highest recovery stress of shape memory polymer composites [88]. CNTs/thermoplastic polyurethane fibers with high stretchability (>1500%) and high electrical conductivity were prepared by Fan et al. in 2012, which are suitable for stretchable conductive fibers. By immersing TPU multi filaments into CNT dispersion in CHCl3, the conductive elastic CNT/thermoplastic polyurethane fibers were prepared. They reported that the achieved fibers have multifunctional applications and are suitable for industrial fabrication [89].

Application of CNT for textile Wastewaters

Safe drinking water is one of mankind's most basic needs. The available supplies of water are decreasing and researchers are seeking alternative sources of water such as wastewater and industrial wastewater. A method for the removal of *Escherichia coli* from water using as-produced and modified/functionalized carbon nanotubes with 1- octadecanol groups(C18) under the effect of microwave irradiation has been investigated[90]. They reported that, low removal rate (3–5%) of (*E. coli*) bacteria was obtained when CNT is alone but if combined with microwave radiation, the unmodified CNT were able to achieve removal rate up to 98% of bacteria from water.A higher removal of bacteria (up to 100%) was achieved when CNT-C18 was used under the same conditions [91]. Textile wastewaters are mostly non-biodegradable and toxic. For treating the environmental pollution, semiconductor photo catalysis can be used. One of the most important photocatalysts is TiO2, but suffers from narrow light response range and low efficiency. Combining TiO2 with CNT can increase the photocatalytic activity [92-94]. For increasing the rate of photocatalytic oxidation of water pollutants, CNT/TiO2composite was prepared by Ming-liang et al. in 2009 using MWCNT and titanium as sources [95]. The photoactivity of the composite was evaluated by the conversion of methylene blue in aqueous solution under UV irradiation. They concluded that the methylene blue removal effect of the CNT/ TiO2composites is related to electron transfer between MWCNT and TiO2 and adsorption of MWCNT and the photocatalytic degradation of TiO2. Jauris et al. studied the interaction between SWCNT and two synthetic dyes (Methylene Blue and Acridine Orange). They concluded that, where the dyes are parallel and planar to the nanotubes due to a predominance of π–π interactions between dyes and nanotubes; these configurations are stable. SWCNT can be used for commercial purpose in the real textile wastewater treatment and are potential adsorbents for the removal of dyes and also by growing the nanotube diameter, the binding energy between dyes and nanotubes increases.

Filters

Fabrication of Carbon nanotubes filters using electro aerodynamic deposition of aerosolized CNT at room temperature and atmospheric pressure was first reported by Park and Hwang in 2014. Carbon nanotubes were coated on a sample of glass fiber air filter medium. CNT with 50 nm diameter and 2–3 μm length were aerosolized, electrically charged, and injected through a nozzle and were deposited on the sample in a vertically standing posture even at a low flow velocity. It was concluded that CNT filters had better filtration efficiencies with 92% antiviral efficiency. The susceptibility constant of virus to CNT was 0.2 cm2/μg and these CNT filters can be used for both inactivation of viral aerosols and filtration [96].

Yildiz and Bradford prepared a novel filters by drawing aligned CNT sheets and embedding them between polypropylene melt-blown nonwoven fabrics with calendaring method. They compared and pretended their filters with HEPA filters. They concluded that three-layer CNT cross-ply filter met the HEPA filtration criteria and had the highest quality factor.

Jimenez-Suarez, Campo, Prolongo, Sanchez, and Urena in 2016 reported that by adding more than 0.2 wt. % of non-functionalized CNT in the epoxy resin for manufacturing multi-scale-reinforced composites, filtration effects are modified.

Anti-microbial activity of CNT

There is an increasing need for antibacterial materials and fabrics in many applications. Kang et al. in 2007 reported that, highly purified single-walled carbon nanotubes (SWNT) exhibit strong antimicrobial activity and it was the first direct evidence [97]. CNT can adsorb bacteria. SWNTs are much more toxic to bacteria than MWNT. Carbon nanotube adsorption technology has the potential to remove the natural organic matter, bacterial pathogens, and cyanobacterial toxins from water systems. CNT have fibrous shape with large accessible external surface area, high aspect ratio, and well-developed mesopores. The antibacterial activity of SWCNT with three different lengths (<1 μm, 1–5 μm, and ~5 μm) has been compared in 2010 by Yang et al. They reported that, longer SWCNT exhibited stronger antimicrobial activity at same weight concentration.

Longer SWCNT aggregated with bacterial cells more effectively but short length SWCNT tended to aggregate without involving many bacterial cells. The aggregation between bacterial cells and CNT cause cell death.

The antibacterial activity of CNT against the microbes such as *L. acidophilus*, *B. adolescentis*, *E. coli*, *E. faecalis*, and *S. aureus* were evaluated by Chen et al. in 2013 (Chen et al., 2013). They reported that, CNT including SWCNT (1–3 μm), short MWCNT (s-MWCNT: 0.5–2 μm), long MWCNT (l-MWCNT > 50 μm) and functionalized MWCNT (hydroxyl and carboxyl modification, 0.5–2 μm), all have broad-spectrum antibacterial effects.

In another research, by the exhaustion method, carbon nanotubes were coated on the surface of cotton fabric. SHP as a catalyst and BTCA as a cross-linking agent was used. MWCNTs have a positive effect on antibacterial

properties of the coated cotton samples. Zinc oxide (ZnO)-1, 2, 3, 4-butanetetracarboxylic acid (BTCA) and ZnO-BTCA-carbon nanotube (CNT) composites were synthesized by Yazhini and Prabu in2015. The synthesized materials were coated on cotton fabric by pad-dry-cure method separately. The fabrics were tested against gram positive *Staphylococcus aureus* and gram negative *Escherichia coli*. They concluded that the ZnO-BTCA-CNT-coated fabric has very good antibacterial activity in compare with the ZnO-BTCA-coated fabric.
In 2013, photocatalytic and antibacterial carbon nano fiber decorated with TiO2/ZnO composite nanoparticles was prepared by Pant et al. Electro-spinning method for poly acrylonitrile followed by calcinations and hydrothermal treatment was used. They reported that, loading of a little amount of ZnO nanoparticles during electro-spinning can be effective for better stability of TiO2/ZnO particles on the surface of the fibers. Also it was found that carbon–TiO2/ZnO has a stronger antimicrobial effect in compare withTiO2/ZnO nano composite. Effect of plasma pretreatment on the absorption of carboxylated carbon nanotubes on the surface of cotton fabrics was also investigated.
CNT were applied on plasma-pretreated cotton fabric by exhaustion method. It was found that the plasma treatment is effective on improving CNT absorption by cotton fabric. Also antibacterial activity of cotton fabric when modified by low-temperature plasma and stabilized with CNT was improved [98].

6. Conclusion

Carbon nanotubes are highly conductive, lightweight and owing distinct physical and chemical properties and have created a new interesting field in textile industry for the continuous investigations. For fabricating conductive textile composites, carbon nanotubes are a promising candidate cause of their unique properties. CNT-coated textiles have various applications in wearable electronics and smart textiles. CNT can be used in smart textiles and electronic textiles, scaffolds, structural health monitoring and flexible sensors, fire retardant and UV protection textiles, composite reinforcements, nano reactors, etc. Also, CNT could cover a wide range of textile functions from flame retardant fabrics to antibacterial textiles by the integration of different kind of CNT with different applied production method.

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