Carbon Nanotubes (CNTs) Futuristic Body Armor

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Abstract

The body armours used by defense sector are not reliable when it comes to lethal weapons, modern bullets, and explosives with shrapnel. Carbon Nanotubes(CNTs) are very small, light-weight, and many times stronger than steel and Kevlar. The fascinating physical, mechanical, and electrical properties of CNTs are ideal for futuristic ballistic armour incorporated with electronics and microsensors. This paper provides an insight into the various applications by CNT'S which will enable new defense applications, including; smart lighter anti-ballistic body armours, wearable computers, switchable camouflage capable of solar energy storage and protection against chemicals and biological gases.

Introduction

The defense personnel and civilians fatalities have been increasing in the recent years. There is an urgent need to provide better security against terrorist's violence. At present, the bulletproof vests are made of Kevlar, Twaron, and Dyneema. These can provide protection from low to medium level but not sufficient protection to high calibre bullets and modern weapons. These materials also have some major weaknesses like high cost, bulkiness and discomfort in wearing.

Nanotechnology gives a new idea that "small and smart" is more relevant. Carbon nanotubes (CNTs) brought revolutionary technological changes for a wide range of military applications and have potential to change the face of humankind.

CNTs are tubular forms of carbon that can be envisaged as graphene sheets (two-dimensional graphite planes) rolled into a cylindrical form. Carbon nanotubes are extremely small; the diameter of one carbon nanotube is one nanometer, which is one ten-thousandth (1/10,000) the diameter of a human hair. Each nanotube is made up of a hexagonal network of covalently bonded carbon atoms.

Carbon nanotubes can be produced to varying lengths. Scientists have developed three main methods to create CNTs: arc discharge, laser ablation, and chemical vapour deposition (CVD)[1,2].CVD is the most popular method for commercial production.

CNTs are of two types: single-walled and multi-walled. A single-walled carbon nanotube (SWNT) consists of a single graphene sheet rolled up into a cylindrical shape, whereas a multi-walled carbon nanotube (MWNT) comprises several concentric graphene cylinders. The different structures have individual properties that make the nanotubes appropriate for different applications [1,2]. For body armours, single-walled nanotubes are preferred for their superior mechanical properties.

Current Body armors

The latest bullet-proof vests are made of layers of fibrous materials. Upon impact the material absorbs the energy of the bullet and disperses it throughout the material. This slows down the bullet and stops it from penetrating the body [3].

High performance fibers and yarns commonly used for ballistic protection are S-glass, aramids (e.g., Kevlar 29, Kevlar 49, Kevlar 129, Kevlar KM2, Twaron), highly oriented ultra high molecular weight polyethylene (e.g., Dyneema, Spectra), PBO (e.g., Zylon) which is a p-phenylene-2-6-benzobisoxazole,

new polymeric fibers such as Polypyridobisimidazole (PIPD) (referred to as M5) etc. These fibers are characterized by low density, high tensile and compressive strength, high modulus, high rupture strain, resistance to thermal degradation and high-energy absorption capacity [4].

These are generally sufficient for domestic protection; the disadvantage to

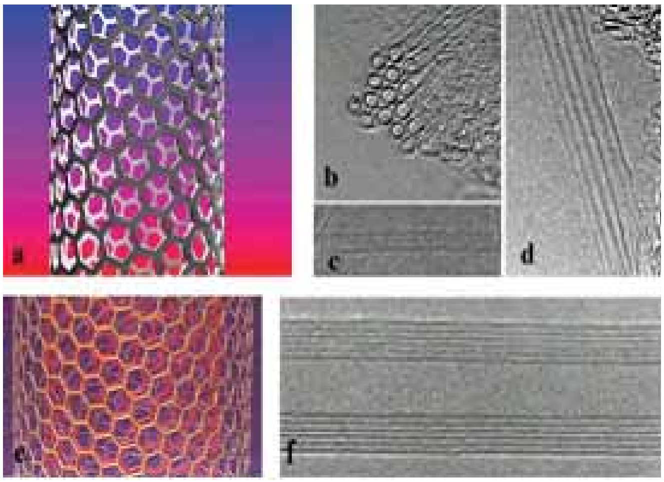


Fig. 1. Structure of Single-Walled (SWNT) (a-d) and Multi-Walled (MWNT) carbon NanoTubes (e,f). (a) Shows a schematic of an individual helical SWMT. (b)Shows a cross-sectional view (TEM image) of a bundle of SWNTs [transverse view shown in (d)]. Each nanotube has a diameter of 1.4 nm and the tube-tube distance in the bundles is 0.315 nm. (c) Shows the high-resolution TEM micrograph of a 1.5 nm diameter SWNT. (e) is the schematic of a MWNT and (f) shows a high resolution TEM image of an individual MWNT. The distance between horizontal fringes (layers of the tube) in (f) is 0.34 nm (close to the interlayer spacing in graphite)

Pictures Source: Pulickel M. Ajayan[1] and Otto Z. Zhou[2] .Applications of Carbon Nanotubes.

these types of armors is that the wearer of the vest is still forced to absorb all of the energy possessed by the projectile, resulting in blunt force trauma, possibly causing injury to the wearer. The effects of this can vary from the wind being knocked out of the wearer, bruising of the skin or even fatal injuries to the internal organs. A superior bullet-proof vest would instead deflect both the bullet and the majority of the energy possessed by the bullet away from the wearer reducing the possibility of blunt force trauma [3].

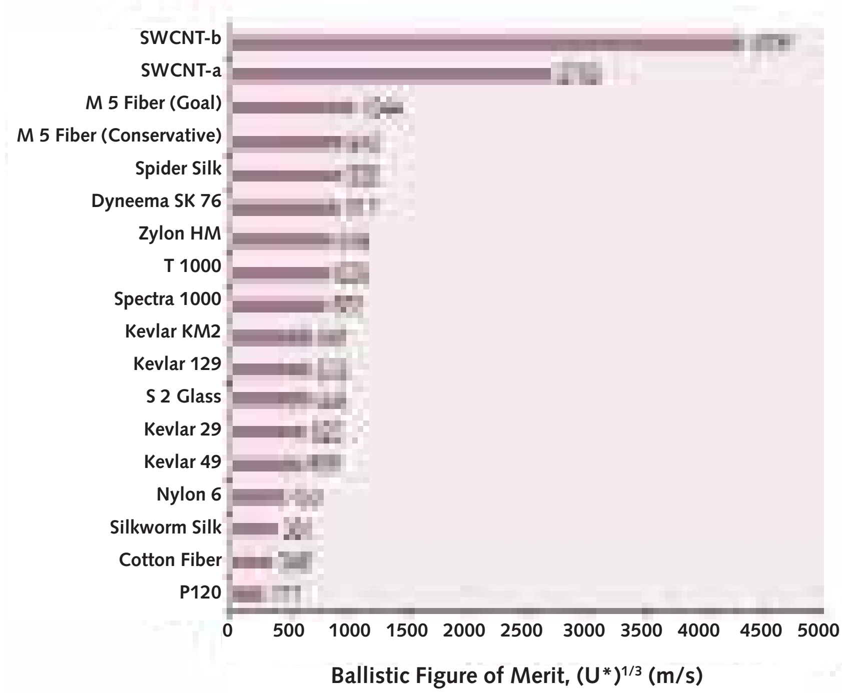
Potential of CNTs for futuristic body armor

The idea of smart defense clothing has come up with the advent of nanotechnology. CNTs offer a promising future as a ballistic armour due to their extraordinary properties like high tensile strength (30~60Gpa - 100 times stronger than steel per unit of weight), Young's Modulus of (1 Tpa), 40% strain to yield in tensile tests, high energy absorption capacity and low weight. A Ballistic figure of merit U* for ballistic applications has been proposed where

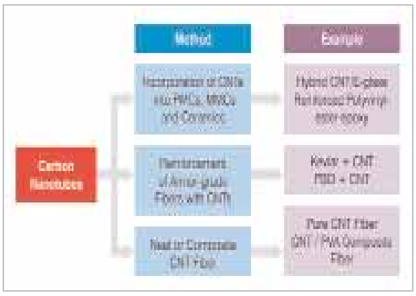
$$U^*[m/s]^{1/3} = \left[\frac{\sigma\varepsilon}{2\rho}\sqrt{\frac{E}{\rho}}\right]^{1/3}$$

There are three different approaches for utilizing carbon nanotubes to enhance the ballistic performance of body armor.

1. Incorporation of CNTs into PMCs (polymer-matrix-composites), metals or ceramics to enhance their hardness or toughness and erosion resistance.
2. Use of neat or composite fibers of CNTs in the form of woven or non-woven fabrics, for achieving exceptional ballistic performance.
3. Reinforcing the armor grade fibers like Kevlar, UHMWPE (Ultra high molecular weight polyethylene) or PBO with CNTs to improve their elastic modulus and energy absorption capacity [4].



Source: Dr. V K Saraswat-Advanced Composite Materials & Technologies for Defence.



Worldwide Research and Developing Technologies

Worldwide commercial interest in carbon nanotubes (CNTs) is reflected in a production capacity that presently exceeds several thousand tons per year [5].

"CNTs as ballistic armour" is one of the most robust growth areas of research around the globe. Many researchers around the world are developing and studying them for commercial applications. The major powers of the world (US, UK, China, Australia, France, and Canada) are making significant strides to develop new generation lightweight, body armours based on CNTs technology.

Mylvaganam and Zhang have shown that this technology has the capability of bouncing off a bullet with body armor comprising six layers of carbon nanotube yarns, each of 100 μm thickness, and muzzle energy of 320 J [6].

Amendment II introduced a new ballistic armor named as "Rynohide". They claim that this is the world's first commercially available cost effective Carbon Nanotube armor and is much: lighter, stronger, more flexible, thinner and has less back-face deformation (how far the bullet pushes into you), which means it hurts less when shot [7].

A lot of ballistic textile research and development is conducted at the US Army Natick Soldier Research, Development and Extension Center, Natick, Mass., in collaboration with fiber and ceramics companies, academic institutions and other entities, with a goal of developing ever lighter-weight, higher-performance materials that can improve soldiers' mobility, performance and comfort.

Natick is currently working on a project with Nanocomp. They are producing small amounts of carbon nanotube yarn and nonwoven sheet materials in its researchscale facility. Nanocomp. is preparing to open a 40,000-square-foot pilot facility, and within the next three years plans to open a 100,000 square foot production facility that would produce more than 1 million kilometers of yarn and 50 acres of 3-by-6- and 4-by-8-foot nonwoven sheets annually [8].

The Institute for Soldier Nanotechnologies (ISN) is an interdepartmental research centre at MIT. The ISN's mission is to use nanotechnology to dramatically improve the survivability of soldiers. The ultimate goal is a futuristic, nanotechnology-enabled battle suit that provides superior protection from ballistic, chemical, and biological threats and offers autonomous medical monitoring and intervention. The ISN currently has eleven industry partners, including DuPont and Raytheon, who collaborate on research and will transition promising laboratory results into real products for soldiers, police, firefighters, and other first responders [9].

The MIT's researchers are now working on CNTs-based sensors to detect a wide range of harmful gases and solar cells for high energy storage [10].

The Stanford Robust Systems Group, however, has made significant progress in the last 18 months, advancing from building individual carbon nanotube transistors to simple electronic circuits made by interconnecting the transistors, and this week to a complete computer made from an ensemble of just 142 low-power transistors. I.B.M. has also been more vocal and optimistic about the potential for CNTs[11].In the coming days, switchable

camouflage and wearable clothing with tablet computers will be made from CNTs.These suits can adjust body temperature and perform operations with the help of solar energy.

CNTs for electronic applications are still a strong focus for research. CNTs and their compounds exhibit extraordinary electrical properties, and have a huge potential in e-textiles such as switchable fabrics for improved thermal control sensors for body and brain sensing, environmental and situational awareness, wearable computers/displays for visual feedback-integrated into a smart bulletproof vests, suits, socks or helmet ,and energy conversion devices such as solar cells.

Conclusions

CNTs, CNTs-based nanocomposites, and their yarns(due to their remarkable properties) have great potential to revolutionize the defense industry through lightweight, durable, high performance, and comfort bulletproof clothing with interesting functions like: improved, thermal control and solar energy storage, barrier against chemical and biological gases, sense distant sounds of vehicles or movement of enemies etc. I think it's an intriguing field and there is tremendous scope in this area.

The CNTs research is driving new developments and it will open new horizons. As a result, useful modern defense applications will be available for the betterment of society.

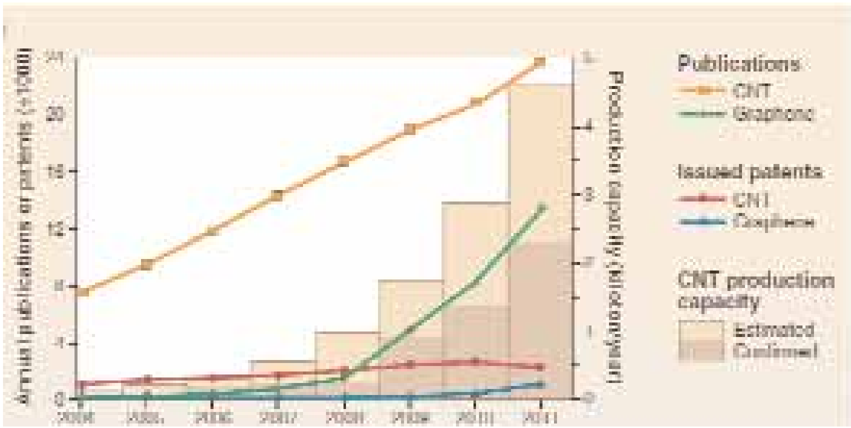


Fig. 1. Trends in CNT research and commercialization. (A) Journal publications and issued worldwide patents per year, along with estimated annual production capacity [6]

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