Carbon Nanotubes in Engineering Applications: A Review

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***Abstract*-Carbon nanotubes are molecular-scale tubes of graphite carbon that possess superior properties. They are the strongest and stiffest fibres with Young's modulus 1 TPa and maximum tensile strength of 63 GPa. Carbon nanotubes are widely used in Biological, Chemical, Medical, Material Science and Engineering applications. This review outlines the engineering applications of carbon nanotubes and discusses benefits and concerns associated with their uses. Many research works have been done on this particular topic and various technologies have been proposed and applied at experimental and field levels. It is planned to identify the applications of carbon nanotubes from engineering point of view.**

Keywords- Nano Tubes; Nano Technology; Engineering Applications

I. INTRODUCTION

Nano technology has recently become one of the thrust areas in research and development worldwide and has also attracted considerable attentions in the media and investment community [1]. Nano technology represents a combination of classical, natural, mathematical, computer and material sciences, investigating and manipulating physical matter on the scale of nanometres [2].

Nano technology development started in the 1990's after the discovery of Nobel Prize-winning technique, scanning tunnelling microscopy and atomic force microscopy. These techniques enabled the visualization and handling of small scale physical matter with exceptional accuracy [2]. Nano technology was named as "the sixth truly revolutionary technology introduced in the modern world."

Carbon nanotubes take the form of cylindrical tubes and are allotropes of carbon [3]. CNTs are having novel properties such as small dimensions, strength and remarkable physical properties which allow them to be potentially useful in a wide range of applications in nanotechnology such as engineering, electronics, chemical, optics, biological, medicine and material science applications. Carbon nanotubes are categorized mainly into two types:

A. Single Walled Carbon Nanotubes (SWCNT)

SWCNTs are generally manufactured by using arc discharge technique [3]. Their purity range is about 95-98 Wt% and include roughly 92-95 Wt% of carbon nanoparticles. SWCNTs diameter range is about 0.7 to 2 mm and form a bundle which measures 8nm. It requires no special refinery processes. They are having high aspect ratio and also high crystallinity [4] together with element characteristics of excellent arc discharge. SWCNTs are used in sensors, conducting transparent electrodes, nanodevices etc. SWCNTs have superior thermal and electrical conductivity with excellent mechanical strength [3].

B. Multi Walled Carbon Nanotubes (MWCNT)

MWCNTs are generally manufactured by using of thermal chemical vapour deposition (CVD) technique [3, 5] and do not require any special refinery process. Its diameter range is of 10 to 30nm and its purity percentage is 95%. MWCNTs are apt for CNT metal composites and for polymers. The structure of Single walled (SWCNT) and multi walled (MWCNT) are shown in Fig. 1. Single walled and multi walled CNTs similarly have superior thermal [6] and electrical conductivity with excellent mechanical strength. Also they are having high length to diameter ratio, high crystallinity and specific surface area [3].

CNTs have several applications such as composite materials, energy storage, conducting paints, chemical sensors (Electrostatic discharge, heat exchanger, reinforced material and electro-magnetic interface shielding). This paper reviews some engineering applications of CNT without focussing on synthesis/fabrication.

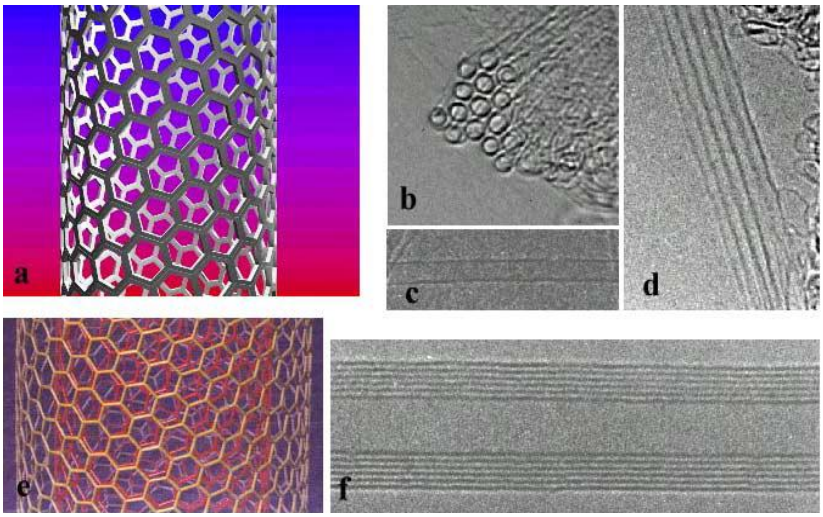

Fig. 1 Structures of single walled carbon nanotube (a-d) and Multi walled carbon nanotube (e, f)

C. Engineering Applications of CNTs

1) Vacuum Microelectronics:

For technological applications, investigation on electron field emission materials are done extensively, such as microwave amplifiers, flat panel displays etc. Also for technological applications, the emissive electron materials should be stable at high current density and should contain low threshold emission fields. CNTs have exact combination of properties – chemical stability, high electrical conductivity, structural integrity, nanometer size diameter – that make good electron emitters. Clear advantageous properties are shown by carbon nanotube emitters when compared to conventional emitters in terms of current density and threshold electrical field, for high resolution display applications, their emission site density is yet too low [7]. A graph is shown in Fig. 2, representing the current density versus electric field.

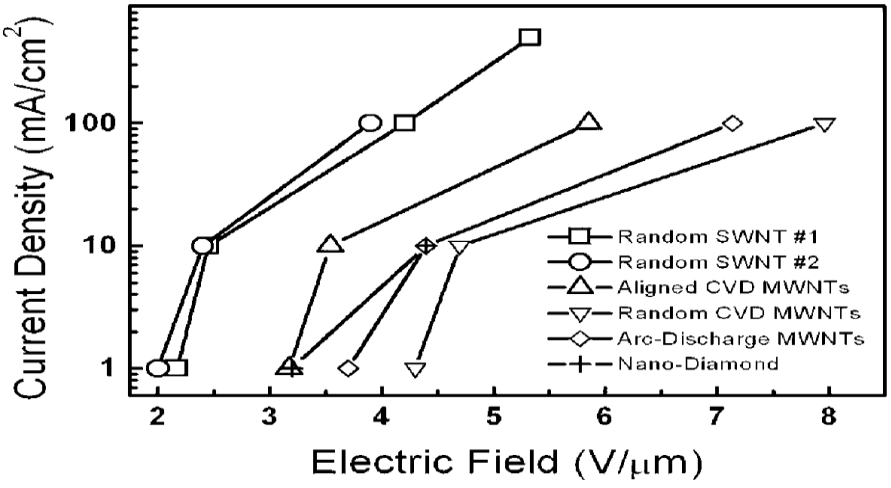

Fig. 2 For different forms of carbon nanotubes, electric field vs. current density are measured [7]

2) Storage of Energy:

Generally for storage and production of energy carbon nanotubes are being considered. Carbon fibre electrodes, carbon containing materials and Graphite are been used for decades in electrochemical batteries, fuel cells and many various applications. Due to their perfect surface specificity, smooth surface topology, small dimensions and because of the exposure of basal graphite planes in their structures nanotubes are uniquely recognised [7].

3) Filled Composites:

Carbon nanotubes have exciting mechanical behaviour because nanotubes are considered to be "the ultimate" carbon fibre that is ever made. The specific strength of carbon fibres are about fifty times that of steel, in composites the load-bearing reinforcements are excellent. For structural applications exactly suited nanotubes should be considered. Carbon fibres have been used as reinforcements in high performance composites, less weight, high strength; one can typically find these in a range of products ranging from expensive tennis rackets to aircraft body parts and spacecraft [7].

4) Sensors and Nano Probes:

Due to uniform and small dimensions few interesting applications will be produced by nanotubes. With flexibility, high mechanical strength, high conductivity and extremely small sizes nanotubes utility as nano probes may finally become absolutely necessary. Nano probes have wide range of applications in drug delivery, field emitters, sensors etc. [7].

Nanotubes are also utilized as chemical sensors. On exposure to ambient gaseous molecules of oxygen, NH3, and nitrogen the SWNTs electrical resistivity changes sensitively. Through observing differ in conductivity of nanotubes, the gaseous presence could be monitored precisely. The nanotube sensors response times are faster when compared to polymer and (solid state) sensors. Also the high surface area and small dimensions provides better sensing applications for nanotubes at different temperatures.

5) Templates:

Nanotubes have relatively narrow and straight channelled cores, which made it possible to fabricate one-dimensional nanowires by filling these cavities with foreign materials. Nanotubes consist of strong capillary forces that they are capable of holding fluids and gases inside them. Hence they can be used as templates [8].

6) Reinforcement of Turbine Blades:

The main challenges for marine current turbines include high bending forces, cavitations, dynamic effects, high flow velocity fluctuation resulting from waves and turbulence, higher thrust and higher operational torque that impose larger load to the gearbox. The body of marine current turbine should be designed with sufficient strength to survive in the ocean. Carbon nanotubes can be used as reinforcing agents to improve the strength of marine current turbines [9].

7) Radio Frequency Components:

CNTs resonance frequencies generally differ from few hundred MHz to a several MHz, also CNTs have some interesting mechanical properties that by applying tension to suspended CNTs, mechanical resonance frequencies can be tuned widely. This made the possibility of CNT based wide-range tunable RF components such as nano transceivers, and tunable filters [10].

8) Coating:

Monitoring and maintenance work for marine current turbines is a major challenge as the device is submerged in the ocean. One of the challenges is the attachment of marine microorganisms on the body of marine current turbines. The formation of the micro-organisms is known as the bio-fouling. Bio-fouling incurs adverse effects on marine current turbines. Fouling on the surface of the blade can cause deterioration on the blade and leads to failure of the blade. Carbon nanotubes are used in coatings and can reduce the effect of bio-fouling due to their nano structure and hydrophobic nature [9].

9) Other Applications:

Combining the electrical, thermal and mechanical properties of CNTs with polymers could render a vast range of potential applications. A number of studies have been done to use these properties for industrial applications such as air filtration [11], electronics, sporting goods, automobiles, graphene based noble metals [12], water purification [13], catalytic applications etc. Due to its exceptional structural, mechanical, electrical, thermal and optical properties of CNT, the area of applications seems to be endless in nature, which can bring remarkable changes into our lives. Though there are some significant challenges, they could be subdued with time.

II. LITERATURE REVIEW

In the recent years, several research works have been carried out and nanotechnology has been extensively introduced in many major fields such as medical, biological, material sciences, chemical, engineering etc. Motivated by the importance of the applications of carbon nanotubes (CNTs) in different fields and also the challenges in developing the concepts of carbon nanotubes by various research works, the authors have pulled in some attempts to review the technology applications of carbon nanotubes (CNT's) (Table 1).

TABLE 1 RESULTS OF THE LITERATURE REVIEW

S.No	Results	References
1	• Huge potential has been predicted for nanotechnology applications in construction.	[1]
2	• Nanotechnology applications in reproductive medicine. • Reproductive medicine and Reproductive biology applications.	[2]
3	• Synthesis of CNTs through different methods. • Properties of CNTs. • CNTs and graphene have the power to alter properties of materials which can be exploited in variety of uses.	[3]
4	• Increase in ductility and strength of plates for cutting tools • Reducing their brittle fracture sensitivity.	[4]

5	• Filtration applications of nanofibre research and technology. • Bio-medical applications and protection.	[5]
6	• Synthesis and of carbon nanofibres. • Fabrication of carbon nanofibres. • Properties of carbon nanofibres.	[6]
7	• Several applications of carbon nanotubes with emphasis on material sciences.	[7]
8	• Using template method hollow pipe & porous hollow activated carbon fibre was prepared.	[8]
9	• Application of CNT's in marine current turbines. • Proposing the utilization of CNT's in marine current technology	[9]
10	• Fabrication of nano electro-mechanical system (NEMS) using CNT. • Physical properties of CNT based NEMS. • Applications of CNTs.	[10]
11	• Electro spinning technique for preparation of nanofibres. • Benefits of using nanofibres practically in filter media (composite).	[11]
12	• Exploiting and optimizing advantages of Noble nano materials have been integrated with graphene.	[12]
13	• Remarkable accomplishments of CNT membranes in terms of water permeability, desalination, capacity, robustness, energy savings & scalability.	[13]

III. SCOPE FOR FUTURE WORKS

This review describes many potential carbon nanotube applications with respect to engineering field. A small message the authors wants to deliver through this study is that the unique structure, dimensions and topology of carbon nanotubes led to create a good perfect fibred carbon material. Nanotubes have remarkable physical properties and create a lot of application possibilities, extending the applications of already existing carbon fibres, but a bunch of possibilities based on mechanical and electro-novel behaviour of nanotubes.

Enthusiasm in this field arises because of the multifaceted nature of the material and also due to its perfectly well-defined crystal properties. Nanotubes truly serves as a barrier between the molecular realm and the macro-world, and are predicted to be beneficial in future technology.

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