Vol 3|Issue 1| 2013 |12-17.

International Journal
of
Pharmacy Review & Research
www.ijprr.com

e-ISSN: 2248 – 9207
Print ISSN: 2248 – 9193

REVIEW ON POTENTIAL APPLICATIONS OF CARBON NANOTUBES AND NANOFIBERS

Raghvendra* and Amlan Mishra[1]

*Department of Pharmaceutics, Aligarh College of Pharmacy, Aligarh, Uttar Pradesh, India.
[1]Department of Pharmacology, Smt. Vidyawati College of Pharmacy, Jhansi, Uttar Pradesh, India.

ABSTRACT

Nanomaterials, which are materials with structural units on a nanometer scale in at least one direction, are the fastest growing area in materials science and engineering. Material properties become different on the nanoscale: for example, the theoretical strength of materials can be reached or quantum effects may appear. One-dimensional and quasi-one-dimensional materials such as nanotubes and nanowires demonstrate many extreme properties that can be tuned by controlling their structure and diameter. Nanotubes, nanowires, and nanofibers are not only excellent tools for studying one-dimensional phenomena, but they are also certainly among the most important and promising nanomaterials and nanostructures. The role of nanomaterials in industries is growing. Nanofibers are already used for insulation and reinforcement of composites, and many materials and structures incorporating nanotubes and nanowires are under development. This article presents a brief review on carbon Nano-tubes as well as Nanofibers. An attempt is also made to overview on the potential applications of Nano-tubes and Nanofibers.

Key words: Carbon Nanotubes, Nanofibers; Nanomaterials, CNFs, VGCFs, VGCNFs, CNTs, Nanotechnology.

INTRODUCTION

Nanofibers and Carbon Nanofibers

Nanofibers are defined as fibers with diameters less than 1000 nm nanometers. They can be produced by interfacial polymerization, electro-spinning, and force-spinning. Carbon nanofibers are graphitized fibers produced by catalytic synthesis. Carbon nanofibers (CNFs), vapour grown carbon fibers (VGCFs), or vapour grown carbon nanofibers (VGCNFs) are cylindrical nanostructures with graphene layers arranged as stacked cones, cups or plates. Carbon nanofibers with graphene layers wrapped into perfect cylinders are called carbon nanotubes. Carbon is the building block of a myriad of organic and inorganic matter around us. It is a versatile atom capable of joining to other atoms in *sp*, sp^2, and sp^3 hybridized structures giving rise to millions of stable molecules. In its single element form, it has a number of allotropes (polymorphs) like diamond, graphite, and fullerenes with different properties ranging from extremely hard to very soft scope. Carbon can be made to form tubular microstructure called filament or fiber. The unique properties of carbon fibers have expanded the science and technology of composite materials in recent decades. VGCFs (Vapour Grown Carbon Fiber) and their smaller size variant, VGCNFs (Vapour Grown Carbon Nanofiber) are among short carbon fibers that have drawn lots of attention for their potential thermal, electrical, frequency shielding, and mechanical property enhancements [1]. They are being more and more utilized in different material systems like composites thanks to their exceptional properties and low cost. Carbon nanofibers (diameter range, 3–100 nm; length range, 0.1–1000 µm) (Fig. 1) have been known for a long time as a nuisance that often emerges during catalytic conversion of carbon-containing gases. The recent outburst of interest in these graphitic materials originates from their potential for unique applications as well as their chemical similarity to fullerenes and carbon nanotubes.

Potential Applications of Nanofibers

- Medical: artificial organ components, tissue engineering, implant material, drug delivery [2], wound dressing, medical textile materials.

***Corresponding Author** **Raghvendra** E mail: raghvendra_mpharm@rediffmail.com

- Protective materials: sound absorption materials, protective clothing's against chemical and biological warfare agents, sensor applications for detecting chemical agents.
- Textile: sport apparels, sport shoes, climbing, rainwear, outerwear garments, and baby diapers.
- Filtration: HVAC system filters, HEPA, ULPA filters, air, and oil, fuel filters for automotive, filters for beverage, pharmacy, and medical applications.
- Napkins with nanofibers contain antibodies against numerous biohazards and chemicals that signal by changing colour (potentially useful in identifying bacteria in kitchens).
- In wound healing nanofibers assemble at the injury site and stay put, drawing the body's own growth factors to the injury site.
- Filter media for new air and liquid filtration applications, such as vacuum cleaners.
- Dye-sensitized solar cell
- Pigments for cosmetics
- Energy: Li-ion batteries, photovoltaic cells, membrane fuel cells.
- Carrier materials for various catalysts
- Photocatalytic air/water purification
- Micropower to operate personal electronic devices via piezoelectric nanofibers woven into clothing.

Applications of Carbon Nanofibers

The applications of Carbon nanofibers may be listed as follows:

- Field electron emission sources
- Composite materials
- Scanning probe microscopy tips
- Carrier material for various catalysts in petrochemistry
- In vertically-aligned arrays, a platform for gene delivery. (See Impalefection)
- For electrode materials [3]
- Oil spill remediation

Carbon nanotubes and nanofibers are graphitic filaments/whiskers with diameters ranging from 0.4 to 500 nm and lengths in the range of several micrometers to millimetres. Carbon nanofibers and nanotubes are grown by the diffusion of carbon through a metal catalyst and its subsequent precipitation as graphitic filaments [4-6].

Carbon Nanotubes

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, [7] significantly larger than for any other material. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials. For instance, nanotubes form only a tiny portion of the material(s) in (primarily carbon fiber) baseball bats, golf clubs, or car parts [8].

Figure 1. **Images for Carbon nanofibers**

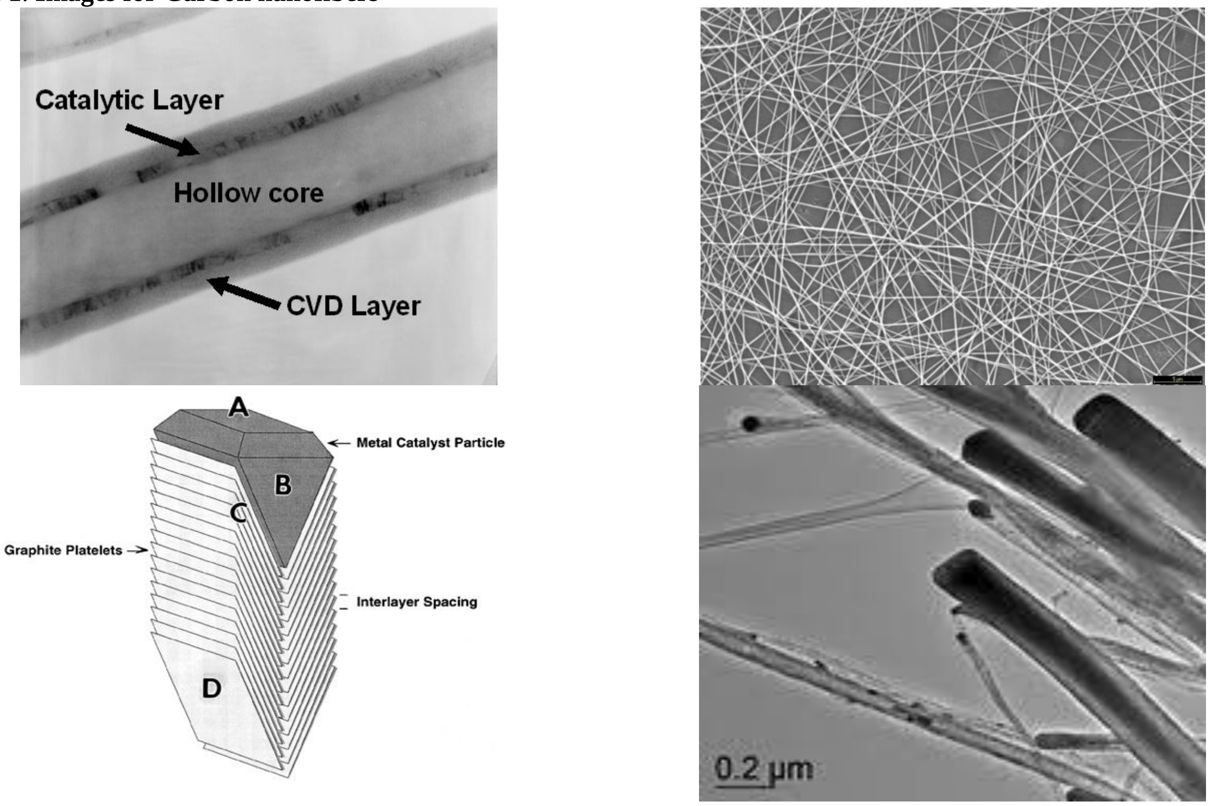
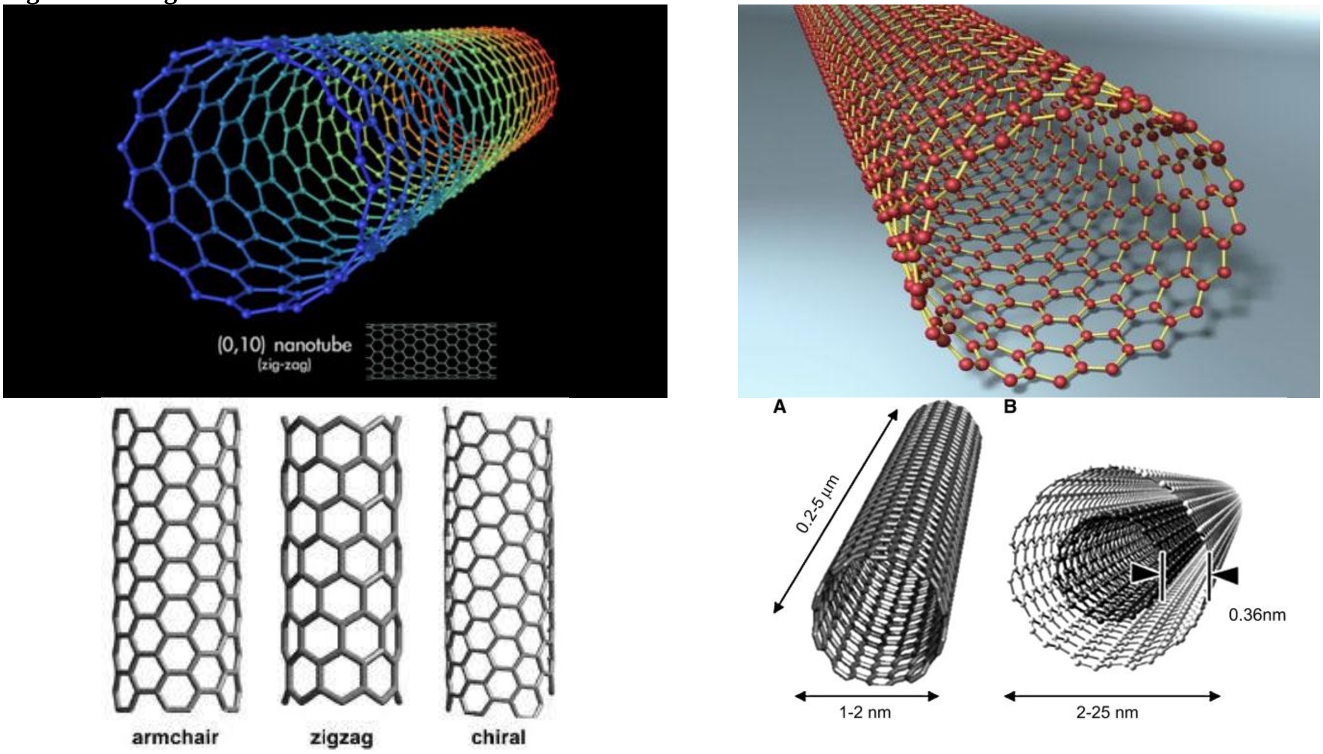


Figure 2. Images for Carbon nanotubes



Nanotubes are members of the fullerene structural family (Fig. 2). Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete ("chiral") angles and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Individual nanotubes naturally align themselves into "ropes" held together by Van der Waals forces, more specifically, pi-stacking. Applied quantum chemistry, specifically, orbital hybridization best describes chemical bonding in nanotubes. The chemical bonding of nanotubes is composed entirely of sp^2 bonds, similar to those of graphite. These bonds, which are stronger than the sp^3 bonds found in alkanes and diamond, provide nanotubes with their unique strength. Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus respectively.

This strength results from the covalent sp^2bonds formed between the individual carbon atoms. In 2000, a multi-walled carbon nanotube was tested to have a tensile strength of 63 gigapascals (GPa) [9]. Further studies, conducted in 2008, revealed that individual CNT shells have strengths of up to ~100 GPa, which is in agreement with quantum/atomistic models. Since carbon nanotubes have a low density for a solid of 1.3 to 1.4 g/cm^3, its specific strength of up to 48,000 kN·m·kg^{-1} is the best of known materials, compared to high-carbon steel's 154 kN·m·kg^{-1}. Under excessive tensile strain, the tubes will undergo plastic deformation, which means the deformation is permanent. This deformation begins at strains of approximately 5% and can increase the maximum strain the tubes undergo before fracture by releasing strain energy. CNTs are not nearly as strong under compression. Because of their hollow structure and high aspect ratio, they tend to undergo buckling when placed under compressive, torsional, or bending stress [10].

Potential Applications of Carbon Nanotubes

- Current use and application of nanotubes has mostly been limited to the use of bulk nanotubes, which is a mass of rather unorganized fragments of nanotubes. Bulk nanotube materials may never achieve a tensile strength similar to that of individual tubes, but such composites may, nevertheless, yield strengths sufficient for many applications. Bulk carbon nanotubes have already been used as composite fibers in polymers to improve the mechanical, thermal and electrical properties of the bulk product.
- Easton-Bell Sports, Inc. have been in partnership with Zyvex Performance Materials, using CNT technology in a number of their bicycle components—including flat and riser handlebars, cranks, forks, seat posts, stems and aero bars.
- Zyvex Technologies has also built a 54' maritime vessel, the Piranha Unmanned Surface Vessel, as a technology demonstrator for what is possible using CNT technology. CNTs help improve the structural performance of the vessel, resulting in a lightweight 8,000 lb boat that can carry a payload of 15,000 lb over a range of 2,500 miles.
- Amroy Europe Oy manufactures Hybtonite carbon nanoepoxy resins where carbon nanotubes have been

chemically activated to bond to epoxy, resulting in a composite material that is 20% to 30% stronger than other composite materials. It has been used for wind turbines, marine paints and variety of sports gear such as skis, ice hockey sticks, baseball bats, hunting arrows, and surfboards.
- Other current applications include:
- tips for atomic force microscope probes in tissue engineering, carbon nanotubes can act as scaffolding for bone growth [11].

Illustrative Applications of Carbon Nanotubes (CNT)

Carbon nanotubes, a type of fullerene, have potential in fields such as nanotechnology, electronics, optics, materials science, and architecture. Over new applications have taken advantage of their unique electrical properties, extraordinary strength, and efficiency in heat conduction. Carbon nanotubes have valuable qualities as structural materials. Potential uses include:

General Applications

- **Textiles**—CNT can make waterproof and/or tear-resistant fabrics
- **Body armor**—MIT is working on combat jackets that use CNT fibers to stop bullets and to monitor the condition of the wearer. Cambridge University developed the fibres and licensed a company to make them.
- **Concrete**—CNT in concrete increase its tensile strength, and halt crack propagation [12].
- **Polyethylene**—Adding CNT to polyethylene can increase the polymer's elastic modulus by 30%.
- **Sports equipment**—Stronger and lighter tennis rackets, bicycle parts, golf balls, golf clubs, and baseball bats.
- **Space elevator**—CNT are under investigation as possible components of the tether up which a space elevator can climb. This requires tensile strengths of more than about 70 GPa.
- **Synthetic muscles**: Due to their high contraction/extension ratio given an electric current, CNTs are ideal for synthetic muscle.
- **High tensile strength fibers**—Fibers produced with polyvinyl alcohol required 600 J/g to break [13]. In comparison, the bullet-resistant fiber Kevlar fails at 27–33 J/g.
- **Bridges**—CNT may be able to replace steel in suspension and other bridges.
- **Flywheels**—The high strength/weight ratio enables very high rotational speeds.
- **Carbon nanotube springs**—Single-walled carbon nanotubes aligned in parallel can be elastically stretched for an energy density 10 times greater than that of current lithium-ion batteries, with the additional advantages of long cycling durability, temperature insensitivity, no spontaneous dischange, and arbitrary discharge rate.
- **Fire protection**—Thin layers of buck paper can significantly improve fire resistance due to the efficient reflection of heat by the dense, compact layer of CNT or carbon fibers [14].

Electromagnetic Applications

CNT can be fabricated as electrical conductors, insulators, and semiconductors. Applications include:

- **Artificial muscles**—CNT's have sufficient contractility to make them candidates to replace muscle tissue.
- **Buckypaper**—Thin nanotube sheets are 250 times stronger than steel and 10 times lighter and could be used as a heat sink for chipboards, a backlight for LCD screens or as a faraday to protect electrical devices/aeroplanes.
- **Chemical nanowires**—CNTs can be used to produce nanowires of other elements/molecules, such as gold or zinc oxide. These nanowires in turn can be used to cast nanotubes of other chemicals, such as gallium nitride. These can have very different properties from CNTs—for example, gallium nitride nanotubes are hydrophilic, while CNTs are hydrophobic, giving them possible uses in organic chemistry.
- **Electric motor brushes**—Conductive CNTs are used in brushes for commercial electric motors. They replace traditional carbon black. The nanotubes improve electrical and thermal conductivity because they stretch through the plastic matrix of the brush. This permits the carbon filler to be reduced from 30% down to 3.6%, so that more matrix is present in the brush. Nanotube composite motor brushes are better-lubricated (from the matrix), cooler-running (both from better lubrication and superior thermal conductivity), less brittle (more matrix, and fiber reinforcement), stronger and more accurately moldable (more matrix). Since brushes are a critical failure point in electric motors, and also don't need much material, they became economical before almost any other application.
- **Light bulb filament**: alternative to tungsten filaments in incandescent lamps.
- **Magnets**—Multi-walled nanotubes (MWNT coated with magnetite can generate strong magnetic fields)
- **Optical ignition**—A layer of 29% iron enriched single-walled nanotubes (SWNT) is placed on top of a layer of explosive material such as PETN, and can be ignited with a regular camera flash [15].
- **Solar cells**—GE's CNT diode exploits a photovoltaic effect. Nanotubes can replace ITO in some solar cells to act as a transparent conductive film in solar cells to allow light to pass to the active layers and generate photocurrent.
- **Superconductor**—Nanotubes have been shown to be superconducting at low temperatures [16].
- **Ultra capacitors**—MIT is researching the use of nanotubes bound to the charge plates of capacitors in order to dramatically increase the surface area and therefore energy storage ability.

- **Displays**—CNTs can be used as extremely fine electron guns, which could be used as miniature cathode ray tubes in thin high-brightness, low-energy, low-weight displays. This type of display would consist of a group of many tiny CRTs, each providing the electrons to hit the phosphor of one pixel, instead of having one giant CRT whose electrons are aimed using electric and magnetic fields. These displays are known as field emission displays (FEDs).
- **Transistor**—CNT transistors have been developed at Delft, IBM, and NEC.
- **Electromagnetic antenna**—CNTs can act as antennas for radios and other electromagnetic devices.

Chemical Applications

- **Desalination**— water molecules can be separated from salt by forcing them through networks of carbon nanotubes, which require far lower pressures than conventional reverse osmosis methods
- **Air pollution filter**—CNT membranes can filter carbon dioxide from power plant emissions.
- **Biotech container**—CNT can be filled with biological molecules, aiding biotechnology.

Mechanical Applications

- **Oscillator**—Oscillators based on CNT have achieved higher speeds than other technologies (> 50 GHz).
- **Nanotube membrane**—CNTs as filters in membranes have a high specific surface area and high flux which results in fast flow rates for gases and liquids. Liquids flow up to five orders of magnitude faster than predicted by classical fluid dynamics [17-19].
- **Slick surface**—Some CNT-based fabrics have shown lower friction than Teflon.
- **Waterproof**—Some CNT-fabrics are waterproof.
- **Infrared detector**—The reflectivity of the buckypaper produced with "super-growth" chemical vapour deposition method is 0.03 or less, potentially enabling performance gains forpyroelectric infrared detector.
- **Radiometric standard**—As a standard of the black.
- **Thermal radiation**—For thermal emission in space such as space satellites.
- **Stealth**—Absorbance is high in wide ranges from FUV to FIR.

Medical Applications

Research at University of California, Riverside has shown that carbon nanotubes are suitable scaffold materials for osteoblast proliferation and bone formation [20]. In the Kanzius cancer therapy, single-walled carbon nanotubes are inserted around cancerous cells, and then excited with radio waves, which causes them to heat up and kill the surrounding cells. Researchers at Rice University, Radboud University Nijmegen Medical Centre and University of California, Riverside have shown that carbon nanotubes and their polymer nanocomposites are suitable scaffold materials for bone cell proliferation and bone formation [21].

CONCLUSION

Nanotechnology is one of the most important technologies in this century and it is evoking a new industrial revolution. Nanotechnology is changing basic research in the fields of information technology, biological science, environmental science, energy sources, material science, and others. The trend of industrial elements toward small features, high density, fast transmission, low energy cost and high production rate has generated a greater requirement of miniaturization for elemental materials. Nanomaterial containing nanostructures are the best material to fulfil these needs. Carbon nanotubes are among the most broadly discussed, researched and applied. Carbon nanotubes are microscopic, tube-shaped structures, which essentially have a composition of a graphite sheet rolled into a tube. Carbon nanotubes have unique, interesting and potentially useful electrical and mechanical properties, and offer potential for various uses in electronic devices. Carbon nanotubes also feature extremely high electrical conductivity, very small diameters (much less than 100 nanometers), large aspect ratios (i.e. length/diameter ratios greater than 1000), and a tip-surface area near the theoretical limit (the smaller the tip-surface area, the more concentrated the electric field, and the greater the field enhancement factor). These features make carbon nanotubes ideal for electron field emitters, white light sources, lithium secondary batteries, hydrogen storage cells, transistors, and cathode ray tubes (CRTs).

Carbon nanotubes can be used in applications that include Field Emission Devices, memory devices (high-density memory arrays, memory logic switching arrays), Nano-MEMs, AFM imaging probes, distributed diagnostics sensors, and strain sensors. Other key applications include: thermal control materials, super strength and light weight reinforcement and nanocomposites, EMI shielding materials, catalytic support, gas storage materials, high surface area electrodes, and light weight conductor cable and wires. Carbon nanofibers find use as battery and composite additives. A nanofiber is an ultra-fine fiber having a diameter of 1-800 nm, and has various physical properties that cannot be gained from a conventional fiber. A nanofiber web, used as a membrane type porous material may be usefully applied to various fields, such as filters, wound dressings, artificial supporters, defensive clothes against biochemical weapons, separation membranes for secondary batteries, and nanocomposites.

REFERENCES

1. Tibbetts GG, Lake ML, Strong KL and Rice BP. A Review of the Fabrication and Properties of Vapour-Grown Carbon Nanofiber/ Polymer Composites. *Composites Science and Technology*, 67, 2007, 1709-1718.

2. Nagy ZK, Balogh A, Vaina B, Farkas A, Patyi G, Kramarics A, Marosi G. Comparison of Electrospun and Extruded Solplus-Based Solid Dosage Forms of Improved Dissolution. *Journal of Pharmaceutical Sciences*, 10, 2011, 227.
3. Rassaei L, Sillanpaa M, Bonn M and Marken MJ. Carbon nanofiber-polystyrene composite electrodes for electroanalytical processes. *Elecroanalysis*, 19, 2007, 1461-1466.
4. Endo M. Review on Carbon nanotubes and fibers. *Chemtech*, 18, 1988, 568.
5. Rodriguez NM, Chambers A, Baker RTK. A description of Nanofibers and Carbon nanofibers. *Languimir*, 11, 1995, 3862.
6. Gavillet J, Loiseau A, Journet C, Willaime F, Ducastelle F,Charlier JC. Potential applications of carbon nanotubes. *Phys. Rev. Lett*, 8727, 2001, 275504.
7. Wang X, Qunging Xie Jing, Jin Zhong, Wang Jinyong, Li, Yan, Jiang Kaili, Fan Shousahan. Fabrications of Ultralong and Electrically Uniform Single-Walled Carbon nanotubes on Clean Substrates. *Nano Letters*, 9(9), 2009, 3137-3141.
8. Gullapalli S, Wong MS. Nanotechnology: A Guide to Nano-objects. *Chemical Engineering Progress*, 107(5), 2011, 28-32.
9. Yu M-F, Lourie O, Dyer MJ, Moloni K, Kelly TF, Ruoff RS. Strength and Breaking Mechanism of Multiwalled Carbon Nanotubes Under Tensile Load. *Science*, 287(5453), 2000, 637-640.
10. Jensen K, Mickelson W, Kis A, Zettl A. Buckling and kinking force measurements on individual multiwalled carbon nanotubes. *Physical Review*, 76 (19), 195436.
11. Haddon, Robert C, Laura P. Zanello, Bin Zhao, Hui Hu. Bone Cell Proliferation on Carbon Nanotubes. *Nano Letters*, 6 (3), 2011, 562–567.
12. Nasibulin AG. et al. A novel cement-based hybrid material. *New J.Phys*, 3(4), 2009, 123-128.
13. Alan B, Dalton et al. Super Tough Carbon-Nanotube Fibres. *Nature*, 423, 2003, 703. Zhao Z, Gou J. Improved fire retardancy of thermoset composites modified with carbon nanofibers. *Sci. Techno. Adv. Mater*, 10, 2009, 155-159.
14. Tseng SA et al. Ignition of Carbon Nanotubes Using a Photoflash. *Carbon*, 45, 2007, 958.
15. Tang ZK et al. Nanotubes as Super Conductor. *Science*, 292, 2001, 2462.
16. David S Sholl, J Karl Johnson. Making High-Flux Membranes with Carbon Nanotubes. *Science*, 312, 2006, 1003-1004.
17. Jason K Holt, et al. Fast Mass Transport through Sub-2-Nanometer Carbon Nanotubes. *Science*, 312, 2006, 1034-1037.
18. Majumder M et al. Nanoscale hydrodynamics: Enhanced flow in carbon nanotubes. *Nature*, 438, 2005, 44.
19. Haddon, Robert C, Laura P. Zanello, Bin Zhao, Hui Hu. Bone Cell Proliferation on Carbon Nanotubes. *Nano Letters*, 6 (3), 2011, 562-567.
20. Xinfeng S, Balaji S, Pham Q P, Liang F,Katherine W, Edward Billups W, Wilson Lon J, Mikos Antonios G. Fabrication of Porous Ultra-Short Single-Walled Carbon Nanotube Nanocomposite Scaffolds for Bone Tissue Engineering. *Biomaterials*, 28(28), 2007, 4078-4090.
21. Balaji S et al. In vivo biocompatibility of ultra-short single-walled carbon nanotube/biodegradable polymer nanocomposites for bone tissue engineering. *Bone*, 43(2), 2008, 362-370.