

Review on Advancement of Carbon Nanotubes Composites

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Abstract—Carbon Nanotubes have been in focus for research since its first observation in 1991. This new form of carbon has shown remarkable physical and mechanical properties. Its potential of applications is increasing rapidly due to its unique electronic and thermal properties, even better than diamond. It is widely used in composites as its properties such as proof resilience, torsional stiffness and strength can be exceeded by other materials thus it is obvious that tremendous opportunities can be offered by carbon nanotubes for the development of new material systems. For polymer also it is widely used as reinforcement due to its high thermal as well as electrical conductivity. It also has flexibility in its properties which give it an advantage for the advanced uses. It is due to its unique structure which is flexible enough to have changes. Structure formation is easy to analyze and can be formulated in various forms. A review of such recent advances in CNT and its composites are elaborated in this paper.

Keywords: Carbon Nano Tube; Chirality; Elastic modulus.

1. INTRODUCTION

As CNT itself is a kind of Fullerene so it is necessary to have knowledge about the same. Chemistry of Fullerenes was introduced by Smalley and at Rice University in the 1980s [1]. These are the carbon structures which are geometrically cage-like and are composed of pentagonal and hexagonal faces. The C₆₀ molecule is the convex and closed structure formed, named after a known architect, systems theorist, author, designer and inventor Richard Buckminster Fuller. It can be described as 60 carbon atoms closed cage which consists of pentagon and hexagon in soccer ball shape so that every side of a hexagon is the succeeding side of a pentagon (It is commonly named as bucky ball) [2]. Few years later, discovery of fullerenes resulted in invention of carbon nanotubes. Carbon nanotubes are fullerenes which have higher value of length and slenderness ratio, where the walls of these tubes are composed of carbon hexagon of graphite hexagon and generally capped from ends.

Due to the consequence of their symmetric structure these cage like forms exhibit exceptional material properties. It has been reported in many researches that mechanical properties of these CNTs have exceeded from those of already existing materials. It has been shown theoretically and experimentally

that CNT's have higher modulus of elasticity greater than 1.1TPa (Elastic modulus of diamond is approximately 1.2 TPa). At a fraction of weight strength of Carbon nanotubes is reported 10–100 times higher than the strongest steel [3]. Therefore, carbon nanotubes and its composites can result a whole new class of advance materials. One must fully understand the fracture and elastic properties of carbon nanotubes as well as interaction at the matrix/nanotube interface to unlock the potential of carbon nanotubes for application in polymer nanocomposites. This interface requirement is similar to the conventional fiber-reinforced composites [4], but the difference is that the scale of the reinforcement phase diameter has changed to nanometers. CNT's are thermally stable till 2800 °C in vacuum [5]. Thermal conductivity of CNT's was reported to be greater than 200 W/m K at room temperature which is close to that of thermal conductivity.

2. CARBON NANOTUBES ATOMIC STRUCTURE AND MORPHOLOGY

Carbon nanotubes are the tubular form of graphite sheet which are rolled into long tubes. As far as geometry is concerned it is quite different from that of diamond. On one hand diamond has a 3 dimensional cubic crystal structure which is generated with carbon atoms respectively, having four nearest atoms arranged in a tetrahedron form whereas graphite is a 2 dimensional sheet of carbon atoms arranged in a hexagonal array and each carbon atom have three nearest atoms. Carbon nanotubes are formed by rolling these sheets into tubes. Atomic arrangement is an important factor for determining the properties of nanotubes. Other factors are dimensions, aspect ratio, morphology and nanostructure. Rolling of these nanotubes leads to formation of single walled (SWCNTs) or multi walled structures (MWCNTs). Multi walled carbon nanotubes (MWCNTs) are made up of concentric single walled carbon nanotubes (SWCNTs) with same center.

2.1. Atomic structure

The distinguishing factor for the atomic structure of nanotubes is chirality rather atomic structure of the nanotubes are

described in terms of the tube chirality, or helicity which is defined by the chiral vector. Chirality is asymmetrical nature of carbon nature in such a way that its mirror image is not superimposable to each other.

In fig. 1 we can see a hexagonal array of carbon atoms which is a general graphene structure. The pattern in which cutting of this sheet will take place is determines the chiral angle. It can be done along the dotted lines and rolling the tube so that the tip of the chiral vector touches its tail. The chiral vector (also called roll-up vector), can be represented by the given equation:

$$\text{Chiral vector} = p\vec{a}_1 + q\vec{a}_2$$



Fig. 1. Chiral vector and chiral angle

Where integer p is the number of steps taken in direction of \vec{a}_1 and integer q is number of steps taken in the direction of \vec{a}_2 .

Chirality or the twist in the tube is determined by chiral angle. Chiral angle can vary between 0° to 30° in which one edge of hexagon is joined with the edge of hexagon in same horizontal level and for second case it is joined in the direction parallel to side. Former case is named as zig zag (for chiral angle 0°) and latter is known as armchair (for chiral angle 30°). Space between the corresponding carbon atoms is known so we can also compute tube diameter from roll-up vector. It is obvious that material properties are affected by tube chirality. Electronic properties are highly affected with tube chirality.

Though sheet of graphite is a semiconductor whose band gap is zero and its structure is also similar to that of SWCNTs but it doesn't mitigate the properties of the same. Graphite is a highly conducting non-metal whereas SWCNTs can be conducting or semiconducting. This depends on chirality or the direction about which the graphene sheet is rolled to form a nanotube cylinder. As discussed earlier these directions are determined by integer's p and q which further denote the direction of chiral vector and band gap depends on them. All armchair SWCNTs are metals which have chirality of 30° as armchair have highest chirality. Also SWCNTs those with numerical value of $p-q=3t$, where 't' is a non-zero integer, are semiconductors. These SWCNTs have a tiny band gap so a higher conducting semiconductor. Remaining SWCNTs are

semiconductors and there band gap is inversely proportional nanotube diameter.

Mechanical properties change due to the effect of chirality has also been investigated. Yakobson et al. [6,7] reported that carbon nanotubes are exceptionally resilient i.e. it undergoes extreme strain due to the application of load and shows no sign of plasticity or brittleness. Other factor which has a significant role in nanotube plastic deformation is Stone-Wales transformation. It is a reversible diatomic interchange of structure two and two pentagons in pairs. This transformation takes place when nanotube with armchair structure is applied to axial stress. Another investigation by Nardelli et al. [8] stated that one of the reasons for ductile fracture that occur during application of stress in armchair structure is Stone-Wales transformation.

2.2. Morphology of Nanotubes

Graphite closed cages which are referred as fullerenes are having a simple structure integrated with pentagon and hexagon units. With the application of tensile or axial stress Stone-Walls transformation takes place. Due to this transformation nanotube structure undergo a new defect where a hexagonal unit is converted into heptagon. Heptagons, thus we can say provides a wider area within the nanotube. It can result in different equilibrium shapes. Rather we can say that most of the nanotubes in the effect of stress are cylindrical but not in straight direction with hemispherical caps.

As shown in fig. 2 this defect is generated due to the application of axial load and thus it is a reason for different mechanical properties of these graphenes.

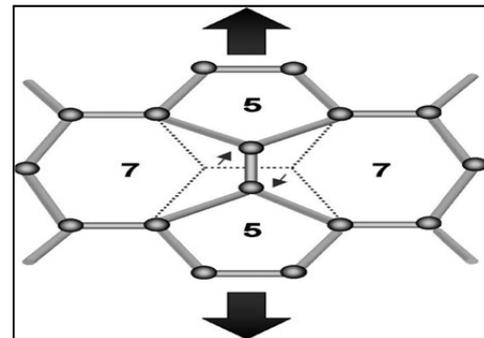


Fig. 2. Defect due to axial loading

Further nanotubes can be classified in other form of existence which is single walled, double walled or Multi walled structure. Nanostructure of a multi-walled carbon nanotube structure is shown in fig. 2 where hollow core is encircled by various nanotubes of different diameters. So it is obvious that Multi-walled carbon nanotubes are concentric single walled carbon nanotubes. It is worth to note that all single walled carbon nanotubes are different in chirality.

3. CNT COMPOSITES

After the realization of excellent properties of CNTs many reports have been generated by fabricating advanced CNT composite. In polymers they are used as conductive filler and are very effective compared to other micro particles. The reason is their high aspect ratio due to their cylindrical shape. Also CNTs have higher thermal conductivity so they are also useful for thermal management. For MMCs it has a break strength reported as high as 200 GPa, and modulus of elasticity in range of 1 TPa. In addition to this it has 500 times more surface area per gram and aspect ratio is as high as 100 approximately.

Grimmer et al. [9] investigated the effect of addition of CNTs in small volume fractions glass-fiber composites. It was observed that cyclic delamination crack propagation rates were reduced to a higher rate. Both sub-critical and critical inter laminar values were increased. It was concluded that the incorporation of carbon nanotubes improved fatigue life twice to thrice in the condition of in plane cyclic loading.

Palza et al. [10] measured the time evolution of the dielectric properties in shear load condition of polyethylene/CNT composite in molten state. It was done by adding a dielectric sensor with high sensitivity into a rheometer (parallel plate type). Initially conductivity was decreased due to the addition of composites in proportion to the oscillatory shear-strain applied. Though, due to a shear-induced agglomeration some composites conductivity increased to a small fraction. Inter molecular spacing between two corresponding CNTs were reduced in such composites just after shear. DC conductivity of the molten matrices were reduced due to the presence of both SWCNTs and MWCNTs at low concentrations (below electrical percolation threshold). These results indicate that in commercial polyethylene, CNTs may act as scavenger for additives or impurities.

Gojny et al. [11] focused on importance of surface functionalization in the mechanical properties of epoxy-based nanocomposites. They investigated that induction of CNTs resulted in increase of strength. An enhanced strength and stiffness and even more important, a significant increase in fracture toughness (43% at 0.5 wt. % amino-functionalized DWCNT) was exhibited by the nanocomposites produced.

Kim et al. [12] studied the microwave absorbers in 8.2–12.4 GHz X-band with parent material E-glass/epoxy composite laminates with reinforcement of various CNTs. For single-layer microwave absorbers complex permittivity solutions were calculated and all possible effect of these solutions on the absorbing bandwidth and the thickness of the absorbers were checked. At a frequency band of 0.5–18.0 GHz, complex permittivity of the E-glass/epoxy composite laminates were measured. This experimentation showed that complex permittivity of all these composites were directly proportional to the concentrations of filler. Also it was depending on the types of fillers and frequency band.

Fiedler et al. [13] studied the effect of processing route (mechanical stirring, sonication and calendaring) and Carbon nanotubes (CNTs) that influenced the degree of dispersion and adhesion between the interface surfaces. Investigation of the resulting mechanical properties (fracture) of the Carbon nanotube/epoxy composites was done for volume contents below 1%. Increase in the fracture toughness (45%) by adding 0.3% of amino functionalized double walled carbon nanotubes (DWCNT-NH₂) was observed.

Odegard et al. [14] compared elastic properties of Single walled CNT/polymer composite by using two approaches—(1) equivalent continuum modeling and (2) Self similar approach. In a continuum-mechanics based model, information about molecular interactions at the nanometer length scale was incorporated in both models. Moreover, it was shown that the both approaches, in a combined range spanning dilute to hyper-concentrated Single Walled CNT volume fractions are useful for predicting elastic properties of single walled carbon nanotubes SWCN/polymer composites.

Martone et al. [15] analyzed dispersed Multi Walled CNTs into an epoxy system focusing on bending modulus. They indicated two limiting behaviors that characterize reinforcement efficiency, whose development of a percolative network of nanotubes coincides with the transition region. At the significant lower level from percolation threshold, the carbon nanotubes enhance the composite modulus with their exceptional modulus (A value of 1.78 TPa was found), whereas above this limit it decreases considerably. The reason behind this is the reduction of the effective (l/d ratio) aspect ratio. Other reason might be the micron sized cluster formation.

Uddin et al. [16] fabricated CNT reinforced copper and copper alloy (bronze) composites by hot-press sintering method. Optimization of the parameters of CNT–metal powder mixing and hot-press sintering was performed. There was 47% improvement in the hardness compared to that of pure copper and 20% increase in electric conductivity was observed. Significant increase in toughness and strength was also observed.

Wu et al. [17] Synthesized polypyrrole (PPy)/multi-walled carbon nanotubes (MWCNT) composites by in situ chemical oxidation polymerization using various concentrations of ammonium peroxodisulfate (APS) and cationic polyelectrolyte poly (styrenesulfonate) (PSS). It was observed that it has a unique feature of high conductivity and solubility.

Lorenz et al. [18] summarized researches on the modal vibration response measurements used to characterize the mechanical properties of fiber-reinforced composite materials quickly and accurately.

4. CONCLUSION

Carbon nanotubes have a unique structure and diverse structural properties which provide it exceptional physical and

mechanical properties. Its low density, hardness and ease to be formed in Nano dimensions enhance its chance to be selected as reinforcement. Moreover its compatibility with metal matrix as well as polymer matrix observed in many researches makes this carbon form a brilliant composite reinforcement. Thermal and mechanical behavior can be understood by knowing about fracture and elastic properties of the reinforcement. There are various techniques to process these composites and characterization of properties can be done for these properties also.

Also properties of composites shows a dramatic change when the size changes from range of micro meter to Nano meter.

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