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3-Point Bending Test of Carbon Nanotubes Reinforced Composites and their Applications

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***Abstract* - For a long time, scientists and engineers have been figuring out ways to incorporate carbon nanotubes in composites. As a result CNTs are being tested in various industries as light, tough and smart alternative to traditional materials. To encompass the increasing demand for CNTs in various industries; more people should be concentrating on improving mechanical, electrical, and chemical properties of these materials. In this article carbon nanotubes reinforced composites (CNRCs) are tested for their mechanical properties using 3-point bend test. CNRCs are exceptionally strong with their performance; declaring them as a potentially good structural material for aerospace and aeronautical applications.**

Index terms - Carbon nanotubes, Composites, Elastic bending

I. Introduction

Carbon is the 6th element on the periodic table making it abundantly available, which is a sign that CNTs are the future materials of industrial revolution. CNT's possess excellent mechanical [1] as well as electrical properties. After the massive discovery of CNT's by Sumio Ijima [2, 3] in 1991; use of CNTs in nanocomposites has significantly increased which are being used in high-tech fields such as aerospace, biomedical, automotive, and naval architecture.

Carbon nanotubes reinforced composites [4-6] are being considered the materials of the future. Various studies have been performed to evaluate the effective material properties of the carbon nanotube reinforced composites using methods such as Molecular Dynamics Simulation, RVE, Rule of mixture [7], Eshelby-Mori-Tanaka approach [8]. Many studies have included experimental approach to verify the theoretical results. From the studies it is understood that the properties of the CNT reinforced composite mainly depend upon the structure of CNT, orientation of CNT, dispersion of CNT within the matrix, fabrication process.

A. Carbon nanotubes

Carbon nanotubes are classified according to the number of concentric walls and their chirality [9]. Chemical bonding of carbon nanotubes possesses the bonds that are found in Diamonds, sp^2-hybrid carbon atoms [10], which provides nanotubes with their unique strength. Chirality of a nanotube is an important property because nanotubes of different chirality have different properties. Chirality of a nanotube is basically an angle to which the graphene sheets are rolled to form the nanotube [11]. It decides whether the tubes are of metallic or semiconducting nature.

Carbon Nanotube's chirality vector is expressed as-

$C_h = na_1 + ma_2$

Where,

$\boldsymbol{a_1}$, $\boldsymbol{a_2}$ are basis lattice vectors

n, m are integers that influence how many hexagonal lattices correspond to a diametric ring of a nanotube and the slope of the arrangement of the hexagonal lattice along the longitudinal axis of the specific nanotube respectively.

The nanotube chiral angle ψ and diameter D are expressed as-

$$\tan\psi = \frac{\sqrt{3}\,m}{2n+m} \qquad D = \frac{r_0\sqrt{3(n^2+nm+m^2)}}{\pi}$$

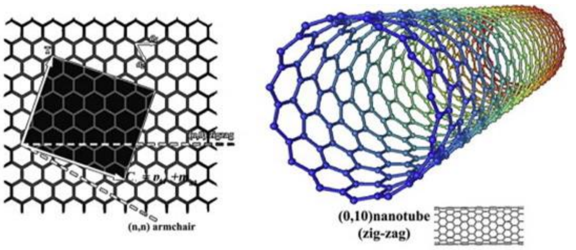

Figure 1 As you can see in the image, there is armchair and zigzag config. Represented by (n,n) for armchair & (0,10) for zig-zag

B. Carbon nanotubes reinforced composites

To explore the elastic behavior of the CNT in a polymer matrix, representative volume element (RVE) [12] is considered in which the polymer matrix is modeled as continuum material while carbon nanotubes as an equivalent long fiber [13]. This makes the calculation easy considering the random dispersion of nanotubes which could lead to infinitely complex model. The properties of the composite material depend upon the volume fraction and orientation of the fibers in the matrix.

Governing equations [14] for elastic modulus of the composite for transverse and longitudinal layouts are given below-

$$E_c = V_m E_m + V_f E_f \tag{1}$$

$$E_c = \left(\frac{V_m}{E_m} + \frac{V_f}{E_f}\right)^{-1} \tag{2}$$

C. 3-point bending test

In this paper, static bending response of a CNRC specimen is obtained using 3-point bending test. Specimen is prepared according to ASTM standard D790 (Standard for reinforced and unreinforced plastics) and test data is recorded. 3 point bending test involves special purpose test fixture on universal testing machine. Specimen rests on two pins which are positioned at a standard distance according to specimen dimensions.

A simplicity of preparation and testing in case of 3 point bending test overpowers its sensitivity towards loading geometry, specimen geometry and strain rate. Test results for load and deflection are plotted against each other as shown in figure 2.

D. Curiosity rover

It is a planetary rover of NASA which explores Martian terrain. Recently, rover's wheels have undergone significant damage. Mars has pointy rocks on its surface. The material of the wheels (aluminum) is unable to sustain the punishing conditions despite various trials on earth. The treads are carrying the rover's weight but they have also reportedly undergone damage along with tears and holes on the aluminum surface [42].

TABLE 1
APPLICATIONS OF CNRCS

Type of the industry	Applications	References
Biomedical	Artificial organs, biosensors, actuators, molecular cargo and drug delivery, bone grafts, knee replacement	[15-21]
Civil and mechanical	Structural reinforcements in columns, composites, coatings and films, wind turbine blades	[22-24]
Aerospace	Space vehicles, stations, radiation shielding materials, wingtips of fighter planes	[25-27]
Electrical	Transistors, chips, non-volatile memory, lithium-ion batteries, super capacitor electrodes, electronics packaging	[28-31]
Automotive	External body parts	[32-36]
Defence	Bulletproof vests, bulletproof cars parts, military aircrafts, warship and missiles	[37, 38]

II. RESULTS AND DISCUSSION

In this article, three phase composites are used, which along with CNTs, have carbon fibers as a reinforcement material. These composites are tested by 3 point flexural testing [39]. Graph for load vs. deflection has been plotted as seen in Figure 2. Curiosity's tyres have faced significant damage due to pointy rocks on the Martian surface [40, 41]. Maximum load is found out to be 1.574e3 N/mm^2 which is higher than what curiosity's tyres are loaded with [42]. New material should be able to withstand the forces exerted by the rocks on mars because of the superior properties.

The cryogenic separation of polymer matrix and fibers remains a huge concern. There needs to be research on additives that can be used to make the composite low temperature resistant.

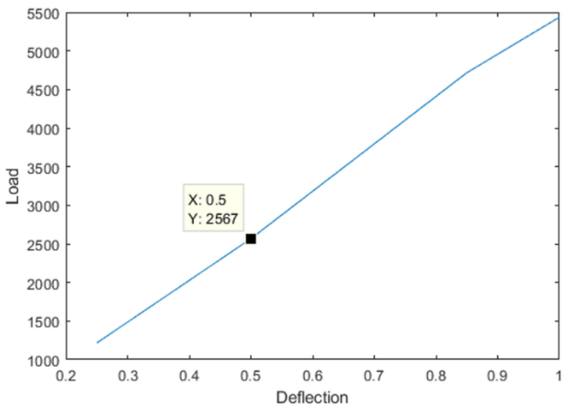

Figure 2 Load vs. Deflection graph-exported through MATLAB

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