Carbon Nano-Particle As A Composite Structure: A Technical Review

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Abstract

The Carbon nanostructures have attracted the many scientists worldwide. The small dimensions, strength and the remarkable physical properties of these structures make them a very unique material with a whole range of promising applications. 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, 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. Carbon nanotubes (CNTs) have been regarded as ideal reinforcements for high-performance composites. Carbon tubes with incredible strength and fascinating electronic properties appear to be ready to overtake fullerenes in the race to the technological marketplace. This paper basically discusses about the Carbon Nano tubes and platelets, techniques for manufacturing, properties and recent advances in this segment.

Keywords: Carbon Nano tubes, Carbon nano platelets, Nano-Composites, Exfoliation.

1. Introduction

What is a composite material?

Composite materials are composed of a mixture of two or more constituents, giving them mechanical and thermal properties which can be significantly better than those of homogeneous metals, polymers and ceramics. An important class of composite materials are filamentary composites which consist of long fibres embedded in a tough matrix. Materials of this type include graphite fibre/epoxy resin composites widely used in the aerospace industry, and glass fibre/polyester mixtures which have wide applicability in the marine and automotive markets. By decreasing the characteristic size of the microstructure and providing large interface areas, the toughness of the composite material is improved significantly compared with that of a homogeneous solid made of the same material as the fibres. In addition, the manufacturing processes of many components can be simplified by applying the fibres to the component in a manner which is compatible with its geometry. These and other considerations mean that composite materials are an effective engineering material for many types of structure.

However, filamentary composite materials are often characterized by strongly anisotropic behaviour and wide variations in mechanical properties which are a direct result of the manufacturing route for a component. In addition, the cost of a composite component is highly dependent on the way the fibres are applied to a surface. This means that designers must be aware of the consequences of manufacturing considerations from the beginning of the development phase [1].

2. Carbon Nano tubes and platelets

The area of carbon nanotube (CNT)–polymer composites has been progressing extremely rapidly in recent years. Nanotubes themselves have remarkable electrical, thermal, and mechanical properties. For example, CNTs theoretically have exceptional mechanical properties such as elastic modulus and strengths 10–100 times higher than the strongest steel at a fraction of the weight [2].

Conducting polymer composites containing conducting filler and insulating matrix are capable of dissipating electrostatic charges and shielding devices from electromagnetic radiation. Graphite nanoplatelets (GNPs) and carbon nanotubes (CNTs) are nano-scaled conducting fillers with very high aspect ratios. GNPs, consisting of several layers of graphene sheets, are often produced by exfoliating graphite intercalated compound, and are of a thickness range on a nanometre scale with a diameter on a micrometer scale. CNTs, consisting of one or more concentric cylindrical shells of graphene sheets coaxially arranged around a central hollow core, have a diameter on a nanometre scale and length on a micrometer scale. With gradually increasing the conducting filler content, composites undergo a percolation transition where the electrical conductivity of the composite jumps up several orders of magnitudes and its nature changes from an insulator to a conductor. This behaviour is attributed to the formation of conducting network through the insulating matrix material when the filler content is at or above the percolation threshold. The percolation threshold of GNP or CNT reinforced polymer nanocomposites is much lower than the conventional fillers, such as metallic particles, carbon fibres and carbon black, due to their extremely high aspect ratios [3].

3. Techniques for fabrication of Carbon Nanotube–Polymer Composites

3.1 Solution casting processing of composites

It is a common method for making polymer–nanotube composites. The procedure involves mixing of nanotubes and polymer in a suitable solvent before evaporating the solvent to form a composite film [2]. The main advantage of this method is debundling and good-quality dispersion of the nanotubes can be achieved. The limitation of this technique is it cannot be utilized for insoluble polymers.

3.2 Melt processing:

It is a good alternative technique to the solution casting process, which is very much useful in dealing with thermoplastic polymers [4]. Furthermore, melt processing is the most promising approach for the production of polymer–MWNT nanocomposites on industrial scale. Normally, melt processing involves mixing of CNTs with the molten polymer by shear mixing. Bulk composites can then be prepared by compression moulding, injection moulding, or extrusion. Advantages of melt processing are its speed and simplicity and easy integration into standard industrial facilities (e.g., extruders, blow-molding machines). Although under high temperatures, this approach can sometimes result in unexpected polymer degradation and oxidation. Melt processing can also be used for the production of both bulk-polymer composites, composite fibers, and yarns [5].

3.3 Electro spinning Technique

It involves electro statically driving a jet of polymer and nanotube dispersions in an appropriate solvent out of a nozzle onto a metallic counter electrode. When the power supply is turned on, the composite solution becomes charged. This forces the solution out of the nozzle and toward the counter electrode. Charging of the solvent causes rapid evaporation, resulting in the coalescence of the composite into fibers with diameters between 10 nm and 1mm. Yarns can also be produced by collecting the fibers on a rotating drum and twisting them [6].

Jing [3] developed analytical model based on an interparticle distance concept, to predict the percolation threshold of conducting polymer composites containing graphite nanoplatelets (GNPs) and carbon nanotubes (CNTs). GNPs are modeled as well-dispersed, disc-shaped cylinders, while CNTs were modeled as either well-dispersed sticks or sphere-shaped CNT agglomerates with a higher CNT concentration than the average CNT content of composites. Two dispersion parameters are introduced in the model to correctly reflect the different dispersion states of CNTs in the matrix. Jing established the relationship between the effect of aspect ratio on predicted percolation thresholds of GNP/polymer and CNT/polymer nano-composites and CNT/polymer nanocomposites as shown in Figure 1. Where, ‘ε’ is the local volume fraction of CNT in an agglomerate and ‘ξ’ is the volume fraction of agglomerated CNTs.

He concluded that -1. The model formulated in this study can be used to establish the correlations between the percolation threshold, dispersion state and aspect ratio of CNTs and GNPs. 2. For perfectly dispersed CNTs or GNPs, the aspect ratio was found to be the predominant factor determining the percolation threshold. 3. For entangled CNT/polymer nano composites, there was a critical value of CNT aspect ratio, above which the two dispersion parameters became crucial allowing the percolation threshold to vary several orders of magnitude, while below it the

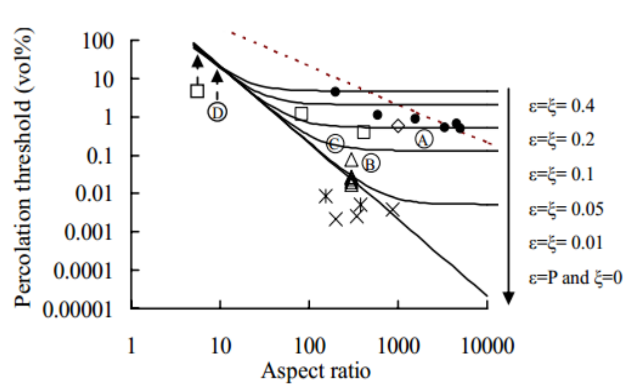

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Fig. 1. Effects of aspect ratio on percolation threshold of polymer nanocomposites containing GNP (dashed line) or CNT (solid lines) [3].

percolation threshold increased rapidly with decreasing aspect ratio. 4. The present IPD model agreed well with experimental data collected from the literature, confirming its applicability to predict the percolation behaviors of nano-composites [3].

4. The Role of Nanotube functionalization

Functionalization of nanotubes is extremely important for their processing and has a direct impact on the mechanical characteristics of CNT–polymer composites. The Y and dY/dVf values of some polymer composites that contain various functionalized and non-functionalized nanotubes are summarized in Table 1 and 2, respectively. As we can see, the highest dY/dVf values are observed for polymers loaded with alkyl-, amine-, or ferritine-protein functionalized nanotubes at very low nanotubes contents (<1 wt%). Normally, nanotube loadings of more than 2 wt% results in a decrease of the mechanical properties due to the aggregation of nanotubes and reduction in nanotube–polymer interaction. In general, there are greater increases in mechanical parameters and dY/dVf values for covalently functionalized CNTs due to more efficient interfacial stress–strain transfer between the nanotubes and the polymer matrix [2].

5. Carbon Nanotube–Polymer Composites Conductive Properties

Conductive nanotube–polymer composites are promising materials for use in lithium batteries, supercapacitors, polyactuators [7]. In particular, new transparent and electrically conductive coatings and films have a variety of fast-growing applications ranging from window glass to flat-panel displays. As in the case of the mechanical properties, the electrical properties of composites based on CNTs are dependent on their processing technique and nanotube content and also correlate with their structure and morphology [8].

Nanotube/Polymer Composite	Nanotube Functionality	Preparation Techniques	Y_{Poly} [GPa]	Y_{Max} [GPa]	NT content [wt%]	dY/dV_f [GPa]
CVD-MWNT/methyl and ethyl methacrylate P(MMA-co-EMA)	Octadecylamine	Solution casting	1.64	2.62	10	15
SWNT/epoxy	Large organic groups	Solution casting and curing	2.02	3.4	4	95
SWNT/polyamide 6 (PA6)	PA6	Solution casting and melt spinning	0.44	1.2	1.5	120
SWNT/PVA	Hydroxyl	Solution casting	2.4	4.3	0.8	305
CVD-MWNT/PVA	Ferritin protein	Solution casting	3.4	7.2	1.5	380
MWNT/PC	Epoxide	Solution casting and injection molding	2.0	3.8	5	95.5
MWNT/PMMA	PMMA	Melt mixing and extrusion	2.7	2.9	3	18.15
CVD-MWNT/PVC	CPP	Solution casting	0.56	0.9	1	115
CVD-MWNT/PS	CPP	Solution casting	1.48	2.63	1	304
SWNT/copolymers of styrene and vinyl phenol (PSVPh)	Carboxylic acid	Solution casting	1.5	2.1	5	24.25
CVD-MWNT/PU	Carboxylic acid	Solution casting	0.05	0.42	20	4.5
SWNT/biosteel (synthetic spider silk)	Octadecylamine	Solution casting	1.6	1.9	0.125	381
SWNT/PAMAM	Epoxy	Solution casting and curing	2.76	3.49	1	153
CVD-MWNT/Kevlar	PVC	Solution casting	1.5	2.5	2	300
CVD-MWNT/epoxy	TETA	Cast molding	1.56	2.4	0.6	355
CVD-MWNT/PS	Butyl	Solution casting	1.29	1.63	0.25	433

Table 1. Mechanical properties of polymer composites containing functionalized CNTs [2].

	Solution Casting			
Nanotube/Polymer Composite	Y_{Poly} [GPa]	Y_{Max} [GPa]	NT content [wt%]	dY/dV_f [GPa]
CVD-MWNT/PS	1.2	1.69	1	74
Arc-MWNT/polyvinylcarbazole (PVK)	2	5.6	8	75
CVD-MWNT/elastomer	0.52×10^{-3}	3.54×10^{-3}	15	35×10^{-3}
CVD-MWNT/PS	1.53	3.4	5	122
CVD-MWNT/high density PE	0.98	1.35	1	57
DWNT/PVA	2	3.6	1	1244
CVD-MWNT/Cl-PP	0.22	0.68	1	72
CVD-MWNT/PVA	1.9	7.04	1	754
CVD-MWNT/PC	2.0	3.3	5	69
Annealed SWNT/PS	2.23	2.275	2	5.04
MWNT/PE	0.682	1.24	5	30
SWNT/epoxy	2.76	3.27	1	107
CVD-MWNT/PVC	1.5	1.76	2	204
SWNT/poly(3-hydroxybutyrate) (PHB)	5.66	11.74	10	125
SWNT/poly(3-hydroxyoctanoate) (PHO)	0.12	0.53	10	8.43

Table 2. Young's modulii and dY/dVf values for CNT–polymer composites produced by Solution Casting technique [2].

Carbon nanotubes provide reinforcement in just one direction; graphite nanoplatelets are effective in two directions. Thus graphite nanoplatelets will yield a higher degree of stiffening and strengthening in most applications where these reinforcements are expected to be randomly distributed. Song [9] investigated the effect of exfoliation on a graphite crystal of a layered structure, which is embedded in a polymer matrix. He found that, when the reinforcement volume fraction is kept constant, more uniform layer separation is shown to improve the stiffening efficiency and reduce the stress concentration in the matrix. The analysis result clearly shows the beneficial effect of full exfoliation. Finite element simulation is carried out to investigate the effect of the level of exfoliation in nanoplatelets on the mechanical properties. Nanocomposites are modeled by a layered structure of graphite nanoplatelets embedded in a matrix. Analysis is carried out for the variation of layer spacing among nanoplatelets which are shown in figure 2, with the constant value of the reinforcement volume fraction. Further the analysis model of nanocomposites is extended to a simplified random distribution of graphite nanoplatelets in order to provide the guideline of exfoliation quality required to improve the mechanical properties. After the analysis it is found that the increase of the vertical spacing in Model B induces the stress concentration in a matrix, but stiffening the nanocomposites.

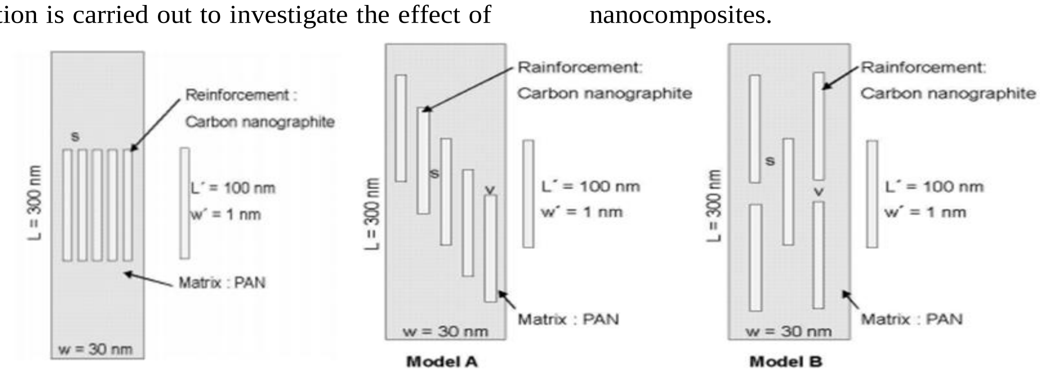

Figure 2. Schematic diagrams of std. regular & simplified random distributed nanocomposites (Model A &B) [9].

6. Mechanical Properties

Effect of Surface Treatments on Mechanical Properties Graphite nanoplatelets treated by O_2 plasma, amine grafting, and acryl amide grafting were prepared and used as reinforcements to fabricate composites with 1.0, 2.0 and 3.0 vol% of graphite flakes. The flexural strength and modulus of each sample are summarized in Figure 3.

The results indicate that the acrylamide grafting was the most effective surface treatment in terms of both strength and modulus enhancements. This is supported by XPS data that showed largest N/C ratio for acrylamide grafting. These data suggest that the amine groups grafted on graphite nanoplatelets improve the compatibility between the graphite nanoplatelets and the matrix and form a bond with the epoxy matrix and improve mechanical properties.

7. Comparison with Commercially Available Carbon Materials

Composites reinforced with PAN based carbon fibers, VGCFs, and nanosize carbon blacks were fabricated. The flexural properties of these composites were measured and compared with those of composites with acrylamide-grafted nanographite. The results are shown in Figure 4. Here acrylamidegrafted nanographite showed the best results in terms of both strength and modulus enhancement. This implies that the acrylamide grafting treatment is a very effective surface treatment for graphite nanoplatelets

Tserpes [11] evaluated the effective elastic properties of carbon nanotube-reinforced polymers as functions of material and geometrical parameters using a homogenized Representative Volume Element (RVE). The RVE consists of the polymer matrix, a multi-walled carbon nanotube (MWCNT) embedded into the matrix and the interface between them. The parameters considered are the nanotube aspect ratio, the nanotube volume fraction as well as the interface stiffness and thickness. For the MWCNT, both isotropic and orthotropic material properties are considered. An analysis is performed by means of a 3D FE model of the RVE. The results indicate a significant effect of nanotube volume fraction. The effect of nanotube aspect ratio appears mainly at low values and diminishes after the value of 20. He also found that The interface mostly affects the elastic properties in the transverse direction and does not influence reinforcement in longitudinal direction.

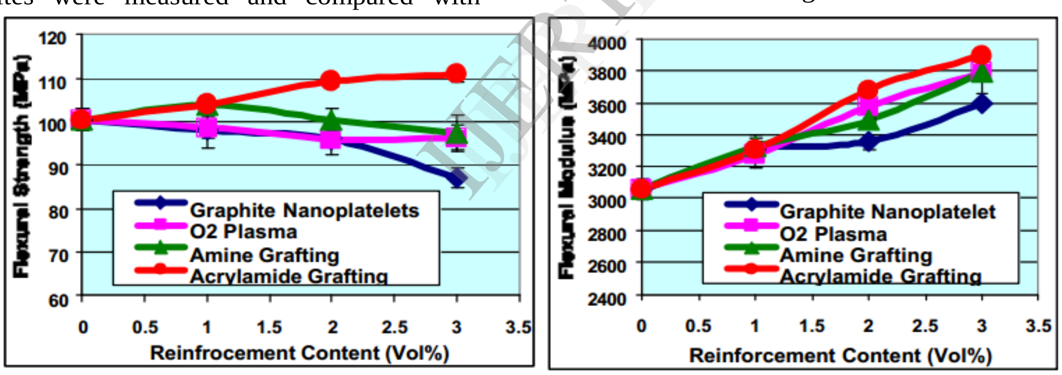

Figure 3 Effect of surface treatment on flexural strength and modulus [10].

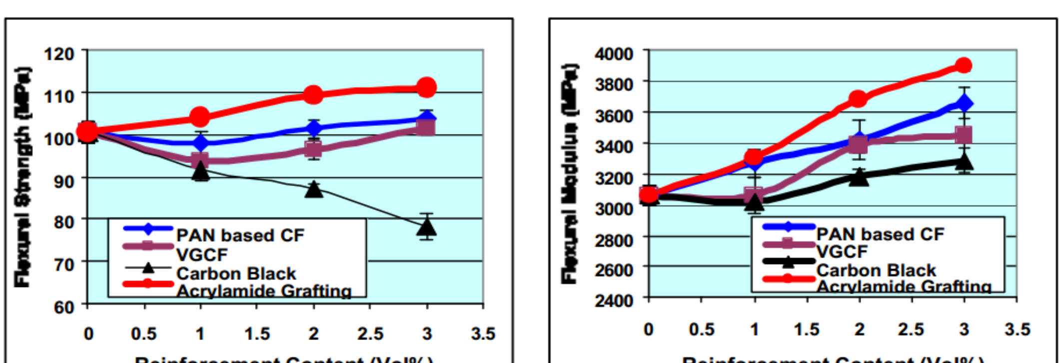

Figure 4 Comparisons of Commercially Available Carbon Materials and Nanographite [10].

Sasha [12] prepared a number of functionalized graphite oxides by treatment of graphite oxide (GO) with organic isocyanates. These isocyanate-treated GOs (iGOs) are exfoliated into functionalized graphene oxide nanoplatelets that formed a stable dispersion in polar aprotic solvents. Characterization of iGOs by FT-IR spectroscopy and elemental analysis suggested that the isocyanate treatment results in the Functionalization of the carboxyl and hydroxyl groups in GO via formation of amides and carbamate esters, respectively.

Otero [13] divided the composite in a matrix and in a new material result of coupling the CNTs with the interface. The relation defined between interface and CNTs assumes that the load is transferred to the nanotubes along their ends and that in the central part the CNTs can develop their full strength. He presented a new formulation, based on the mixing theory, capable of predicting the mechanical performance of composites reinforced with carbon nanotubes. The model presented relates the CNTs and the matrix in which they are embedded, using an interface material. This approach makes possible to consider non-linear phenomenon's, such as CNT debounding, by using non-linear constitutive laws to characterize the interface material.

Ansari [14] modelled a nonlocal Flügge shell model incorporating interatomic potentials is developed to study the buckling behaviour of an axially loaded single-walled carbon nanotube (SWCNT). The theory incorporates the relations resulting from establishing a linkage between the strain energy induced in the continuum and the potential energy stored in the atomic bonds, using the so-called Cauchy–Born rule, into the constitutive relations of Eringen's nonlocal elasticity theory. An exact solution is implemented to solve the set of coupled field equations. In comparison to classical models, the present model provides a much better fit to molecular dynamics (MDs) simulations results and proposes the appropriate value of nonlocal parameter for SWCNTs with simply-supported end conditions.

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Niaki [15] investigated dynamic and static fracture properties of Graphene Sheets (GSs) and Carbon nanotubes (CNTs) with different sizes based on an empirical inter-atomic potential function that simulated nonlinear large deflections of nanostructures. Dynamic fracture of GSs and CNTs are studied based on wave propagation analysis in these nanostructures in a wide range of strain-rates. It is found that wave propagation velocity is independent from strain-rate while dependent on the nanostructure size and approaches to 2.2 x104 m/s for long GSs.

8. Conclusion

Unique structure, topology and dimensions of carbon nanotubes have created a superb all-carbon material, which can be considered as the most perfect fiber that has ever been fabricated. The remarkable physical properties of nanotubes create a host of application possibilities, some derived as an extension of traditional carbon fibre applications, but many are new possibilities, based on the novel electronic and mechanical behaviour of nanotubes. It needs to be said that the excitement in this field arises due to the versatility of this material and the possibility to predict properties based on its well-defined perfect crystal lattice. Nanotubes truly bridge the gap between the molecular realm and the macro-world, and are destined to be a star in future technology. The strength and flexibility of carbon nanotubes makes them of potential use in controlling other nanoscale structures, which suggests they will have an important role in nanotechnology engineering. Not much finite element analysis work on carbon nano platelets is done so far. Hence, there is lot of research scope in this area.

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