Brilliance
Research of Artificial Intelligence

Volume 2, **Number** 3, November 2022
https://doi.org/10.47709/brilliance.v2i3.1692

Carbon Nanotube (CNT) Composites and its Application; A Review

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Article History:
Submitted: 27-08-2022
Accepted: 27-08-2022
Published: 28-08-2022

Keywords:
CNTs; CVD; carbon nanotubes; chemical vapor deposition.

ABSTRACT

Due to their superior mechanical, thermal, electrical, and tri-biological characteristics, carbon nanotubes (CNTs) have been widely used in a variety of industries, from aerospace to energy, since their discovery in 1991. Their compact size, amazing tensile strength, and light weight They are often used as reinforcements in metals, plastics, and even additive manufacturing due to their popularity and conductivity. In this analysis, we present a list of these structures and an in-depth discussion of the CNT-reinforced materials can be processed using a variety of techniques, including chemical vapor deposition (CVD), ball milling, both laser melting and hot pressing. The restrictions in the production and processing of these composites additionally discussed, strengthened by many authored works. To comprehend how these composites' properties change in relation to other parameters, such as a wide range of variables, such as temperature, CNT length, diameter, etc. A summary is given, explaining various methods for performing experimental analysis and providing convincing arguments for putting the changes' causes in. Therefore, we investigate the specialized uses of these CNT-reinforced composites in industries like aerospace, energy, biomedicine, and auto, and how they can be handled further, altered to make room for less expensive and more effective fixes going forward.

INTRODUCTION

It was discovered that the decomposition of hydrocarbons created carbon filaments with very small diameter, at high temperatures, in the presence of catalyst particles, between 1970 and 1980, which is when carbon-based research began to gain pace [1]. When graphite was evaporated by laser irradiation in 1985, creating C60 atoms, this represented a milestone and led to the discovery of fullerene [2]. Carbon-based research has made great strides since the discovery of carbon nanotubes (CNTs) in 1991 [3], finding applications in a variety of industries including electronics, healthcare, additive manufacturing, and more. CNTs are a type of tubular structure with a typical micrometer length and nanometer diameter [4]. Single-walled CNTs (SWCNTs), double-walled CNTs (DWCNTs), and multi-walled CNTs (MWCNTs) are the three varieties that may be distinguished among them [5]. They have tremendous mechanical strength (100 times more than steel) and thermal and electrical conductivity that is comparable to copper thanks to their features, such as extraordinarily high surface areas and enormous aspect ratios. The electrical characteristics of CNTs are significantly influenced by the chirality of these structures [6]. The carbon-arc discharge method, carbon laser ablation, and chemical vapor deposition (CVD) [7, 8] are a few methods for synthesizing these structures that will be thoroughly covered in this paper. CNTs are used in a wide range of industries, including materials science, energy, electronics, sensors, and more. Carbon composites and composites including CNTs as a filler make great advantage of the CNTs' remarkable mechanical capabilities. In contrast, among other uses, the thermal properties can be used for heat dispersion. CNTs can be utilized as sensors because of their high surface-to-volume ratio, which is particularly advantageous for biomedical uses. Due to their high electrical conductivity, CNTs are utilized in electronics as supercapacitors and actuators. In addition to these, CNTs are used in Nano electromechanical devices, hydrogen storage, scanning probe tips, and more [9–11]. Because of their exceptional flexibility and ability to interact with electrically active tissues, CNTs have a wide range of biological applications, including tissue engineering, stimulating neuronal outgrowth, and the development of strong and light prostheses and neuro-prosthetics [12,13]. CNTs do, however, present a number of problems that will require additional study to be overcome [14].Aligning the tubes with the matrix is challenging because of their propensity to stay together in a matrix. It is necessary to produce CNTs in greater quantities and at a lower cost with effective matrix distribution. Material composites that can address the aforementioned problems, are light, have great mechanical and thermal properties, and have a wide range of applications are urgently needed to keep up with the quickly developing industrialization. Although it lacks the better mechanical strength of the latter, graphene is a potential replacement for CNTs in composites [15]. The development of CNT Metal Matrix Composites (CNT-MMCs),

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https://doi.org/10.47709/brilliance.v2i3.1692

which enable us to take advantage of the characteristics of CNTs, such as their high tensile strength and thermal and electrical conductivity, has grown exponentially over the past few decades. With this review, we intend to present a thorough overview of CNTs, the many material processing techniques, their production techniques, various types of experimental analysis, and their influence on the use of CNTs in contemporary society.

LITERATURE REVIEW AND HISTORY

This well-known technique entails creating a thin coating on the surface of a heated substrate by using gaseous vapors in a vacuum. CNT/Al composite foams can be created using it. CNTs can be produced at 600°C utilizing a C2H2/Ar mixture flow and a Co/Al catalyst. The technique can finally manufacture CNT/Al composite powders by cooling it down with an Ar environment [16,17]. By introducing reactant gases into a heated fibrous preform and then allowing them to react to generate a solid phase on the fiber's surface, chemical vapor infiltration can be used in a method similar to this to create composite materials. This allows for the creation of CNT/SiC composites by infiltrating CNT into a chemical vapor infiltration furnace while employing hydrogen as a carrier gas, argon as a diluting gas, and methyl trichlorosilane as a precursor gas [18].

Spray pyrolysis

Spray pyrolysis, in which a fine coating is created on a heated surface by spraying or injecting the precursor, is another technique for creating CNT-metal composites. The precursor CNT-Cu2O can be prepared using this method. The composite powder is created by first dissolving Cu powders and CNT dispersions in deionized water and stirring it magnetically. The resulting solution is then broken down in an ultrasonic nebulizer, and the resulting droplets are then deposited in a heated reactor where solvent evaporation, solute precipitation, precursor decomposition, and sintering are carried out to create the powder [19].

Ball milling

The process of ball milling, which involves grinding the combination into a fine powder in a hollow, rotating cylindrical chamber, is one of the most popular ways to create CNTmetal composites. It is typically done in conjunction with other techniques as cold pressing, spray pyrolysis, and CVD [20-22].

Mechanical alloying

The mechanical alloying process is a dry, high-energy ball milling procedure that includes repeated cold welding, followed by fracturing and then further welding to produce a homogenous composite. Using Al6061 powders as an example, one method for doing this involves alloying zirconia balls, Al6061 powder, and CNTs by putting them all in a zirconia jar and mixing them at up to 1,200 rpm. Alcohol is then added, and the mixture is ultrasonically processed for 60 minutes. The CNTs were disseminated using numerous drops of the solution, each taken independently and diluted. To amalgamate the composite, the treated material was subsequently placed on aluminum foil and subjected to 50 MPa of pressure for 30 minutes [23]. The exact procedure can also be carried out in a tungsten carbide jar revolving at 250 rpm for 6 hours with toluene acting as a process control agent. Spark plasma sintering (SPS) at a pressure of 50 MPa and temperature of 550°C can be used to create the amalgamation [24].

Powder metallurgy

The desired shape is created by combining fine powders, pressing them, and then heating them slightly below their melting temperatures. Utilizing this method, CNT-Al composites can be created by milling Al powder, fly ash, and MWCNTs for two hours at 250 rpm while using methanol as a control substance.The finished product can then be sintered for an hour at 500°C in an atmosphere of argon and cold compacted at 280 MPa [25,26]. As an alternative, the milled mixture may also be hot-pressed for 30 minutes at 580°C in a vacuum at a pressure of 50 MPa [27]. The milled sample can alternatively be solidified using SPS at 550°C and 30 MPa of pressure. A 2,000 kN hydraulic press can be used to execute hot extrusion after preheating at 500°C for 3 min in an Argon atmosphere [28].

Electrophoretic deposition

In order to spread and accumulate electrolyte particles toward the anode surface while in the presence of a strong electric field, this method uses electrophoresis. The result is a coating. CNTs can be integrated into TiO2 films using a voltage of 350 V for 40 s and an electrolyte temperature of 20°C (with ultrasonically pure titanium foil serving as the substrate) [29].

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Process of stir casting

To blend reinforcement in the material matrix, stir casting uses mechanical stirring. This procedure, which is based on the Taguchi method, is used to create composites out of aluminum alloy and CNTs. In comparison to the conventional casting method, the stir casting procedure causes an increase in the hardness values and a decrease in the porosity of the cast metal [30].

Processing using friction stir (FSP)

This technique affects the metal's characteristics through significant deformation and is based on the friction stir welding principle. Powder metallurgy and FSP can be used in combination to create CNT/Al composites. This method can also be used to create CNT/Mg composites, greatly enhancing the product's microhardness. Using FSP, other materials including polyethylene, AlSi10Mg, and Al-Mg alloy can also be reinforced with CNTs.

Colloidal blending

With the addition of CNT, this blending technique produces hot, uniaxially blended composites. This method can be utilized to create CNT-Nickel MMCs with the necessary CNT fractions. An ultrasound bath is used to disperse CNT combined with metallic powder, which is subsequently evaporated to Obtain the specified item [32].Equal-channel angular extrusion (2.1.10) This method contributes to the creation of ultra-fine refined Al composites frequently use materials and. A die the outside corner is used with a 20 mm diameter. For the route BC, angle as 20° and channel angle as 120° with ram speed of 0.8 mm per second [33]. Molecular level mixing (2.1.11) (MLM) This technique involves combining the metal and CNTs. matrix evenly at a molecular level in an aqueous solution level. Using this, Cu composites can be produced. when microwave sintering and MLM are used, technology for rolling. the composite structure should be improved Additionally, cold rolling is an option for sintered CNT/Cu composites. up to 70% and annealed for two hours at 600 °C [34]. Another CNTs can be dispersed in deionized water as an alternative to get a mixture that resembles ink and copper acetate monohydrate can be dissolved in water and stirred with a magnet for 30 minutes It is possible to combine and heat the two solutions. 5 minutes at 75°C, after which NaOH and 2 M glucose can be combined. added. The color must be stirred until it turns brick red. Filtering and vacuum drying can be used to halt the process and create the final composite [35].

Composites, ceramics, and polymers

Pickering emulsion technique

In this process, cellulose nanocrystals are extracted. utilizing acid hydrolysis on micro-fibrillated cellulose, then adding CNTs to the CNC solution. The acquired suspension is ultrasonically and polylactic processed In order to create the Pickering emulsion, acid (PLA) is introduced. It is employed in the production of PLA/CNT/CNC composites compression molding [36] is used.

Infiltration of polymers

In this procedure, CVD-produced CNT films are submerged in a nitric acid and polyvinyl alcohol solution after which CNT fibers are extracted by shrinking the Film CNT [37].

Pressing hot

Heat and pressure are applied concurrently during the densification process known as "hot pressing" to create powders. merely die. At what temperatures is this process carried out? high enough to allow for sintering and creep processes. This method allows the production of WC-Al2O3 cemented carbides reinforced with CNTs [38]. Hot isostatic pressing 2.2.4 (HIP) Densification of materials under extremely high a gas medium's temperature and pressure. To be processed CNT/Si3N4 composites can be sinter-HIP processed in two steps. employed as the pressure medium together with high purity nitrogen [39].

The use of a vacuum bag oven

During this procedure, a flexible bag and vacuum are used to help hold layers together while the drying process is taking place has happened. You may make CNT nanocomposites by this procedure to guarantee process homogeneity [40].

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Drafting done layer by layer (LBL)

Effective preparation of homogeneously dispersed CNTs is achieved by LBL drafting. In the procedure, deposits are made. two interactive elements on the substrate's surface alternately. Any shape or size can be drafted with LBL software. size and offers the distinct benefit of being a simple to without the need for specialized instruments [41], control the process.

SPS

This sintering process uses uniaxial pressure to apply pulsed direct current to electrically conductive die. SPS allows materials to become denser at relatively lower temperatures and with less holding time. B4C This method can be used to densify composites. Punch rods and die made of graphite [42].

METHODS

Additive production

Modeling of fused deposition (MFD)

For reinforced filaments for FDM, CNTs can be mixed with polymers like PLA, thermoplastic polyurethane (TPU), and others. This method can be applied to CNT-yarn-based components printed in three dimensions (3D) conducting polymer nanocomposites based on CNT-graphene [43], functionalized nanocomposite filaments [44], create CNTs/PLA composites [46] and multiaxial force sensors [45]. Powdered polybutylene terephthalate is combined. CNT and graphene, followed by extrusion to create the as a filament in one such method. The FDM process can additionally create Li-ion battery electrodes with CNT, which have improved electron and ion transport abilities [47].

Selective laser melting (SLM)

SLM employs a laser as a power source to melt and the product is created by fusing the metal powder, as demonstrated in Metals reinforced with CNTs can be additively manufactured using SLM, as seen in Figure 2. In such a SLM is used to prepare NiCrAlY-CNT powder for generating substrates with additional lanthanum coatings utilizing plasma spray coating deposition to deposit zirconate. Table 2 exemplifies the SLM process [48]. metallic elements Laser powder bed fusion methods are also used to create titanium alloy powders coated with CNT [49].

Selective laser sintering (SLS)

The SLS method, which uses a laser. power source to sinter the powdered material make the finished item. This method can be applied to Create complex geometric products with ease, as demonstrated High-performance polymers like CNT/alumina composites and CNT-reinforced composites, such as Through the use of SLS, polyether ether ketone (PEEK) can be made. method [50–52].

Digital light processing (DLP)

This method of additive manufacturing relies on curing. Photopolymer resin that employs a focused light source to acquire the item. To create composites with better electrical characteristics, photocurable formulations containing CNTs can be 3D printed using DLP [53].

Direct write printing

The 3D ink utilized in this method is a viscoelastic liquid. without the need for heat or electricity for the manufacturing procedure source of light The dispersion of CNTs in acetone can be sonicated to produce epoxy nanoclay CNT composites. Nanoclay and curing ingredients have also been included. resulting in the creation of ink that is suitable for printing by direct writing [54].

Negative aspects of the CNT composites' methods of preparation

High propensity for simultaneous reactions can be induced by mechanical processing techniques. additional mesoscopic and macroscale processes, such as mixing and structural disordering [55]. the arid The ball milling method has a number of drawbacks, including the size distribution and a reaction with severe non-uniformity Noise, as well as the additional powder material loss,extra contaminants from the grinding media, as well as ultimate products from the grinding jar [56]. Spray pyrolysis is challenging to manage and has a rather uneven distribution of film thickness throughout the substrate's surface [57]. Powder metallurgy has a unique set of disadvantages, including Composite components lack ductility and strength, and there is expensive to use powder materials, and the utilized equipment [58]. Additionally, stir casting has some flaws. (a) an evenly distributed application of reinforcements is necessary to produce a strong-enlarging impact, although a In stir frying, consistent dispersion can be challenging to achieve. casting; (b) the

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https://doi.org/10.47709/brilliance.v2i3.1692

separation of reinforcing particles by the surface of the reinforcement's settlement in melting and casting process; (c) during stir casting, gases and undesirable inclusions may be trapped [59]. SLS may include a cold period of up to 12 hours, extending the production period. Additionally, it results in poor mechanical properties in the samples and has the potential for distortion geometry if the technological processes for wax impregnation are not followed [60]. It is challenging to obtain single-phase material with the annealing process in SLM. internal strains are caused by the step and quenching after annealing. Only basic symmetrical shapes may be used for SPS [61]. Pulsed DC generators must be ready and pricey. [62].

Difficulties in the production of composites

Numerous advantages are provided by CNT reinforcement, including enhancing the electrical conductivity, thermal conductivity, or mechanical strength. But the procedure is not simple because it has its own unique set of difficulties, which which are described below: Chemical functionalization may cause the bonding of substances to Carbon nanosheets Having functions like carbonyl, hydroxyl, carboxyl, and other groups broaden the interface strength between the polymer matrix and the CNTs. Furthermore, they also spread the CNTs out. more successfully. However, chemical functionalization might weaken the mechanical characteristics of the The bonding of graphene sheets is broken by CNT composite [63]. (ii) The dimensions of CNT and matrix powders differ. When CNTs heavier than 1% are employed, they prevent the attainment of necessary qualities. The clusters found in these composites result in lower stiffness, strength, and ductility. Effective Milling can be used to disperse CNTs, however those extreme tension and hardening of the due to the matrix particles, making the processing of the traditional powder metallurgy is used to develop the composite [64]. Van der Waals forces prevent effective CNT dispersion in the matrix (iii) der Waals combatants CNTs tend to have a high aspect ratio, a large specific surface area, and strong van der Waals forces. to cluster, entangle, and agglomerate [65]. This phenomena is quite unwelcome because it CNTs are effectively homogeneously dispersed and can act incorrectly. This aggregation results in weak adhesion [50,67], poor solubility [66], and a significant an increase in the composite's porosity and viscosity Inhomogeneous distribution may have a negative impact [68]. thermal and electrical properties as a result of CNTs in the 3D networks are connected to one another. There have been suggestions to employ straightforward ultrasonic to defeat the potent van der Waals force, dispersion [69], however it's possible that this will lead to bigger issues. Ball milling with high energy might damage the structure of Metal oxides form in an irreversible manner due to CNTs. will reduce the useful mechanical characteristics of an amalgam [23]. Densification, which is required to CNT degradation may also result from processes carried out in CNT/ceramic composites at high temperatures [35, 70]. (iv) Poor bonding at the interface of the CNT matrix The CNT-matrix interfaces proper bonding important part in efficient load transfer between periods [21, 71]. The wettability of metal alloys, nevertheless poses a significant issue and reduces the composite's mechanical strength [68,69]. It may lead to the CNTs could separate from the metal matrix or break apart. Metal-CNT interface [71]. Delamination of composite materials thermally stable, highly chemical resistant, and thermally stable carbon-fiber reinforced PEEK (CF/PEEK) commonly utilized in aircraft and provides stability [72]. Delamination, or material breakage, can yet occur. Applications for these composites are highly qualified. The inadequate interfacial strength between the polymeric matrix and fiber reinforcements is brought about by the CF and's chemical inertness and homophobia PEEK. These composites' tensile strength suffers as oxygen-containing functional groups are added, but their shear strength improves.

RESULT AND DISCUSSION

Contemporary study on carbon nanotube (CNT) composites and their impact on several applications 2637 Tables 11–14 provide a complete overview of the effects of producing CNT–composites on their mechanical, thermal, and other properties. by examining their mechanical, electrical, and tribological properties preparation techniques, test procedures, and characteristics affected and transformed, as well as some potential causes and change.

Applications in aerospace, automobiles, and the military

CNT/polymer composites, such as those made of polyethylene ter - ephthalate (PET), polypropylene (PP), and polyethylene (PE), can be widely employed in both commercial and military applications and have broad frequency ranges for absorption values surpassing 5 dB [74]. They are a great choice for use in the aerospace and automotive industries due to its fracture resistance and damping qualities [127].

In all aircraft structures, CNT/Al composites with outstanding structural strength and functional capabilities are used [82]. The thermal conductivity of IM7 prepreg composites is significantly increased when SWCNTs are added

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https://doi.org/10.47709/brilliance.v2i3.1692

compared to the original material, making them suitable for usage in the low-temperature environment of space. Rockets like the Space Launch System can use CNTs because of their effective heat dissipation, which is required in the pipes and components of aerospace vehicles [40]. The vehicle sector may one day use CNT/epoxy composites because it can significantly boost the water resistance and interlaminar characteristics of these materials [137]. Likewise, due to their excellent strength and EMI shielding capabilities, CNT/SiC composites satisfy the requirements of sophisticated structural vehicles such as spacecraft [138]. A intriguing composite prospect is ink that can be 3D printed with improved mechanical and electrical properties by combining various concentrations of CNTs with nanoclay [54]. Due to their dielectric and water-absorbing qualities, fly ash polymer nanocomposites are also frequently employed in automotive body parts [114].

CONCLUSION

The overview given here demonstrates the fundamentals of CNTs, their fabrication and processing capabilities, and the challenges that must be overcome throughout their production. Given that it produces a homogenous dispersion of CNTs in the metal matrix, ball milling appears to be among the most widely used and effective processes now in use. A thorough investigation showing the various features of these composites that may be seen and examined experimentally is also shown in the paper. The properties of the composite are frequently investigated and estimated using methods like SEM, TEM, X-ray spectroscopy, and nanoindentation. They are used in a variety of industries, including aerospace, electronics, and the biomedical field, thanks to their exceptional mechanical, thermal, tribological, and electrical qualities. Although there has been great progress in the production and synthesis of CNTs over the past few decades, there is still much work to be done in a number of areas, including growth and structure management. The uses of CNTs will be significantly impacted by advancements in these fields, which will also lower the cost of manufacture. By addressing the issues raised in the article, such as inadequate matrix-interface bonding, composite delamination, and inadequate CNT dispersion, the production of CNT-composite materials will be streamlined and their use in various industries will increase

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