Research Journal of Material Sciences ISSN 2320–6055
Vol. **5(1),** 7-9, January **(2017)** *Res. J. Material Sci.*

Short Review Paper

Review of the growth and implementation of carbon nanotubes as polymer reinforcement

Prashant Kamble
Department of Chemical Engineering, TKIET Warananagar, MS, India
theprashant01@gmail.com

Available online at: www.isca.in, www.isca.me
Received 30th November 2016, revised 3rd January 2017, accepted 9th January 2017

Abstract

Carbon nanotubes (CNTs) have the potential use in the fabrication of new generation composites. As reinforcement, their sterling characteristics render the desirable features to resultant composites. Carbon Vapor Deposition (CVD) technique has been employed for the growth of CNTs either independently or on the substrate. Mechanics of the growth and working of CNTs are subject to scrutiny. Several effective parameters on the growth are taken under consideration and improvement in the mechanical strength is studied.

Keywords: CNTs, reinforcement, composite, CVD, mechanical strength improvement.

Introduction

Carbon nanotubes (CNTs) have attracted many researchers because of their remarkable qualities. Extraordinary resilience, stiffness and low density thereof are breakthrough in the manufacturing of high strength low weight structures[1].

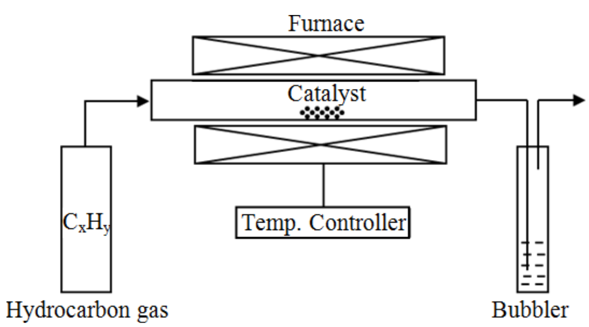

Figure-1: Schematic diagram of a CVD setup in its simplest form[2]

They have a very high aspect ratio with tube diameter on nano-scale and length can exceed 1 mm. Thermal and electrical properties of CNTs are noteworthy in the range of applications[3]. Their one dimensional structure and other novel properties assure the potential application across the field of molecular electronics, field-emission display and nano-composites[4]. So far, CNTs have been extensively tested on different polymer matrices but none of the studies reported composite properties better than that was achieved with carbon fiber reinforced composites. Failure in obtaining the desired mechanical properties led researchers to focus on the growth of CNTs on sorts of substrates such as, carbon fibers, carbon felt/mat, carbon cloth and graphite foil as possible multiphase reinforced composites[5]. This study has investigated the essential aspects of carbon nanotube growth and its application.

Methodology

Carbon nanotube reinforced composites have been mostly developed in two ways:

CNTs growth on the substrate: One of the famous methods to grow CNTs on carbon substrate is Chemical Vapor Deposition (CVD) whereby CNTs are grown on the surface of carbon fiber. In CVD, catalysts such as Fe, Co, and Ni (transition metals) are applied on the carbon surface in particle form[6]. A hydrocarbon gas is injected with the help of a carrier gas (e.g. Argon). Temperature of the system is maintained at a desired level. Ultimately, thermal dissociation of the hydrocarbon gas leads to the growth of carbon nanotubes at the catalyst containing sites on the fiber with catalyst particles either at the tip or at the base of the tube by virtue of adhesive force of the catalyst with respect to surface of the substrate.

Composition: Qian et al. tells about two prominent ways of compositing CNTs with the conventional fiber reinforced composites: i. Dispersing CNTs throughout the composite matrix or ii. Attaching CNTs directly onto the primary reinforcing fiber of the composite matrix. Figure-1 shows the schematic diagram of independent growth of CNTs by CVD.

Mechanism

Growth mechanism: As contended by Kumar et al.[2], researchers yet to reach a consensus on precise growth mechanisms of CNTs however, they agreed upon two rough illustrations of the same.

Tip-growth mechanism: A hydrocarbon vapor when comes in contact with a hot catalyst metal, it dissociates into carbon and hydrogen. Hydrogen flies away while free carbon deposits on the metal surface. Carbon gets dissolved into the metal to the limit of its solubility in the metal at that temperature. Dissolved carbon then gets precipitated out and crystallized in the form of a vertical cylindrical network with metal at the tip, that possibly due to the weak catalyst-substrate interaction since such metal particles subtend acute angles with surface of the substrate[7].

Base/Root-growth mechanism: Base growth has the same explanation for growth except metal remains adhered to the substrate and surrounds the base of the crystallized cylinder of carbon. This can be attributed to the strong catalyst-substrate interaction since such metal particles makes obtuse angles with surface of the substrate[8].

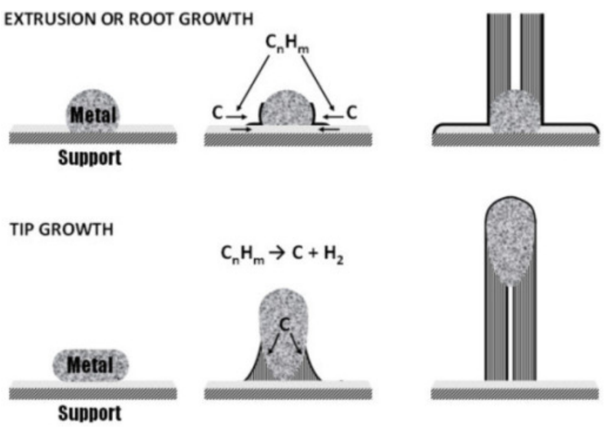

Figure-2: Schematic showing base growth and tip growth of carbon fibers[8]

Load transfer mechanism: CNTs can either be grown or attached on the surface of the primary reinforcing fiber or else can be dispersed throughout the fiber reinforced composite matrix. CNTs anchored to the fibers create bridges or scaffoldings between the filaments. The bonding between the fiber and matrix is a crucial factor which governs the load transfer phenomenon between the composite constituents. Presence of CNTs as fillers of micro pores at the fiber-polymer interface enhances the holding between the fiber and matrix that bolster the solidity of the composite[5]. Figure-3 shows the growth of CNTs on neighboring carbon fibers.

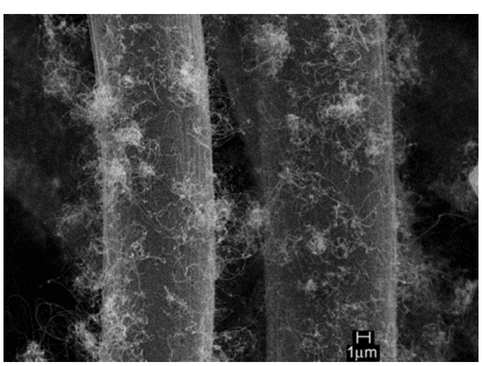

Figure-3: Micrograph of CNTs grown on carbon fiber felt after ultrasonification[5]

Growth measures

The temperature at which the CNTs are grown on the surface of carbon fiber is popularly known as the growth temperature. It has a measurable influence on the density and structure of the CNTs on the fiber surface. Two other parameters also play a significant role i.e. solubility of used hydrocarbon in the employed catalyst with w. r. t. temperature and feed flow rate. As temperature increases, morphology of CNTs changes dramatically from being predominantly aligned and uniform in length to predominantly non-aligned and variable in length owing to the competing nucleation and growth mechanism[9]. Generally, low temperature yields to the Multi Walled CNTs (MWCNTs) while higher temperature is favorable to the formation of Single Walled CNTs (SWCNTs). This contributes common understanding of MWCNTs being easier to grow than SWCNTs as stated by Kumar et al.[2].

Mechanical strength

Mathur et. al.[5] observed that during the initial application of CVD the flexural strength of single carbon fiber decreases with lower fraction of nanotube growth and pick up with increase in volume or wt. % of CNTs. This phenomenon was attributed to the fact that these lower fractions only produce defects and have no role of a true reinforcement. These defects build up the stress concentration in the area cause weakening of the composite. The effect can be nullify with the higher concentration of the tubes so that the strength becomes more than the loss from defects. The trend of flexural strength improvement can be better illustrated with the help of Figure-4.

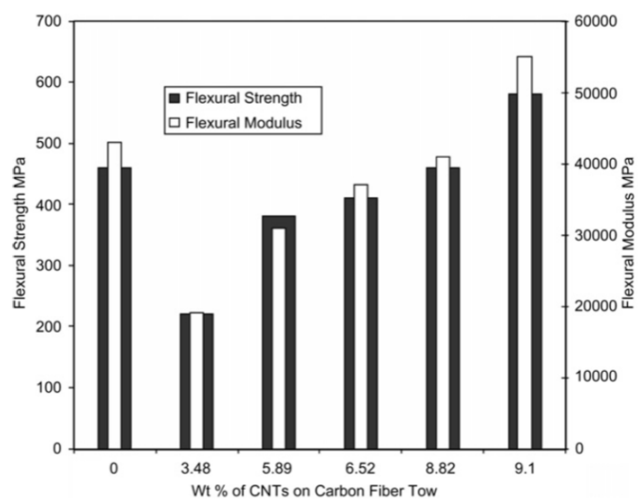

Figure-4: Mechanical properties of composites with increasing nanotube contents[5]

Conclusion

To encapsulate, substantial data is available enough to prove the capabilities of CNTs in the case of high strength and low weight structure building. However, the complete knowledge regarding the same is yet to be attained. Many possibilities of the growth and use are needed to be explored. All in all, the future of carbon nanotubes appear to be interesting.

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