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Carbon nanotubes and other fullerenes produced from tire powder injected into an electric arc

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Abstract

A novel method of growing multiwall carbon nanotubes by injecting tire powder into an electric arc has been developed. The process is optimized using a DC electric arc in pressurized helium. The multiwall carbon nanotube product and the optimization process are characterized by transmission electron microscopy.

Keywords: Multiwall carbon nanotubes; Tire powder; Electron microscopy; Electric arc discharge

1. Introduction

The pyrolyzed growth of carbon fibers or filaments dates to the 1889 patent of Hughes and Chambers [1], which describes the growth of "hair-like carbon filaments" utilizing a feedstock of hydrogen and methane pyrolyzed in an iron crucible. It was thought initially that these fibers would be suitable for electric light bulb filaments. Davis et al. [2] observed twisted carbon filaments about 10 nm in diameter deposited on blast furnace brick work while, around the same time, Iley and Riley [3] grew carbon fibers by decomposing methane, propane, and acetylene at 1200 °C on quartz substrates. Similarly, Hillert and Lang [4] grew a variety of carbon fiber shapes, some straight lengths up to 5 cm, by decomposing *n*-heptane in a silica tube at 1000 °C using catalytic metal particles. Catalytic growth of carbon fibers using metal particles (or CVD growth) was later expanded by Endo and Komaki [5], and processes described in detail by Dresselhaus et al. [6]. Tibbets [7] described the production of carbon fibers by pyrolysis of natural gas in stainless steel tubes and the pyrolysis of other hydrocarbons using iron catalyst, with particles ranging from 12 to 71 nm in diameter [8]. These catalyst-grown (CVD) fibers were actually carbon nanotubes, usually multiwall carbon nanotubes (MWCNTs). Singlewall carbon nanotubes (SWCNTs) were first made by Dai et al. [9] from the disproportionation of CO at 1200 °C using Mo catalyst particles, and later produced from acetylene, ethylene, benzene, and methane using other catalysts such as Fe, Cr, Co [10,11]. MWCNTs were also produced by these catalytic processes [12,13].

Carbon nanotubes (both SWCNTS and MWCNTs) are also commonly prepared by DC electric arc discharge, a modification of the AC electric arc-discharge process originally developed by Kratschmer et al. [14] to mass-produce fullerenes. Iijima [15] originally observed MWCNTs in the cathode deposit for a DC

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Fig. 1. Converted vacuum/pressure chamber for electric arc-discharge system. (a) Chamber exterior view. (b) Open chamber showing arc-discharge arrangement. The arrow shows the adjustable anode system.

electric arc arrangement and have since been produced in relatively large scale DC arcs in He gas [16], and thermally purified [17]. Singlewall carbon nanotubes have also been prepared in a DC electric arc using a metal catalyst-filled graphite anode [18]. The conditions for obtaining good quality MWCNT samples depend upon the plasma (arc) stability, current density, and cooling, especially of the cathode [17]. The average temperature in the arc is of the order of 4000 K. Multiwall carbon nanotube growth has also been promoted in arc-discharge environments with various ambient gases, including He, Ar, and CH_4 [19], and MWCNTs produced by hydrogen arc discharge contain few co-existing fullerenes and other carbon nanoparticulates [20].

Gruenberger et al. [21] have recently described an AC (thermal) plasma arrangement that allows the injection of solid, liquid, and gaseous carbonaceous feedstocks into the plasma flow for the continuous production of bulk quantities of carbon blacks as well as fullerenes and MWCNTs. More recently, Choi et al. [22] have described a method for carbon nanotube production by decomposition of hydrocarbons using an arc-jet plasma. In their experimental work, argon and hydrogen were used as a plasma gas and nickel powder as a metal precursor, while the carbon source was methane.

In the research to be reported in this paper, we have explored the injection of tire powder into an electric arc, and observed its pyrolysis and conversion to carbon nanotubes and related carbon nanoparticulate materials using the transmission electron microscope (TEM).

2. Experimental details

The experimental system was developed from an arc-discharge configuration in a converted vacuum furnace as shown in Fig. 1(a). Fig. 1(b) shows the arc-discharge system within the vacuum chamber. The original system consisted of a 1.3-cm diameter, water-cooled graphite cathode rod in a 10 cm × 10 cm copper target plate; and a 0.6-cm diameter graphite anode. The anode electrode was connected to a movable retractor system (Fig. 1(b)) that allowed the arc to be adjusted. Both AC and DC power supplies, rated up to 150 A, were available for producing a suitable arc.

The primary objective for this experimental arc-discharge arrangement involved the injection of powdered tire matter or tire particulate matter (TPM) into a suitable arc. This was achieved in an experimental mode using an injector design shown schematically in Fig. 2. The injector consists of a glass bulb reservoir with a valve connected to a helium gas source. By adjusting the He gas pressure and the reservoir valve, the TPM could be loosely suspended and drawn into the injector stream with the He gas. This arrangement prevented clumping and plugging of the TPM, and allowed a short

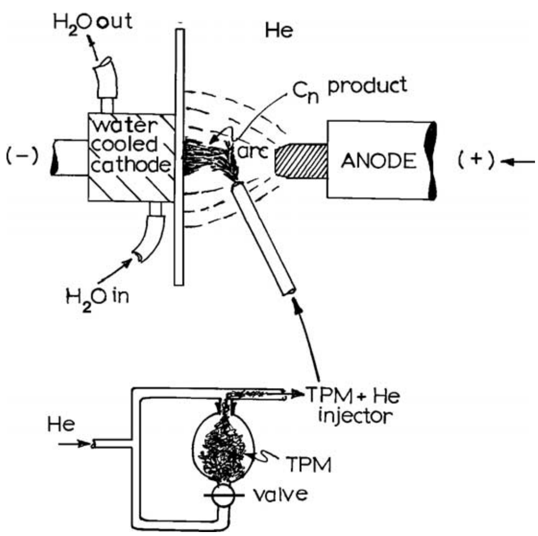

Fig. 2. Schematic diagram of electric arc discharge and tire particulate material (TPM) injector system.