Heating Efficiency of Debundled Carbon Nanotubes Compared to Carbon Black

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ABSTRACT

Carbon nanotubes can be used as heat generating sources when stimulated by infrared light. However, nanotubes aggregate significantly, which may reduce thermal output. This paper compares temperature increases for bundled and separated nanotubes in aqueous media. Further, nano-sized carbon black is compared to carbon nanotubes to determine if nanotubes are more efficient heaters. Results indicate that good dispersion is beneficial and that nanotubes are slightly more effective than carbon black, although this point is negated upon addition of a surfactant to carbon black suspensions.

Keywords: carbon nanotubes, carbon black, dispersion, heat efficiency

1 INTRODUCTION

Carbon nanotubes have strong absorption in the infrared, where body tissues are most transparent. Due to their high aspect ratio, nanotubes behave as antenna, [1] a property which should increase their efficiency to couple to incident radiation and in turn generate heat. Recent literature has shown that single- wall carbon nanotubes, in the presence of infrared stimulation, are able to generate enough heat to kill cells *in vitro*. [2] Therefore, the use of nanotubes for highly-localized thermal ablation therapies seems promising.

Carbon nanotubes are hydrophobic and bundle easily and this may affect their absorption and heating efficiency, especially in aqueous media. For biological applications, nanotubes are typically functionalized to inhibit bundling; however, this may affect biological response, and for heat comparisons with carbon black, it is appropriate for all materials to be unfunctionalized. Although it has been shown that nanotubes conduct heat better than carbon black [3-5] no results have yet shown that nanotubes generate heat better following infrared absorption than other carbon materials. Surfactants are employed to aid in the dispersion of the nanomaterials although nanotubes could likewise be wrapped with DNA,[6] or polysaccharides.[7]

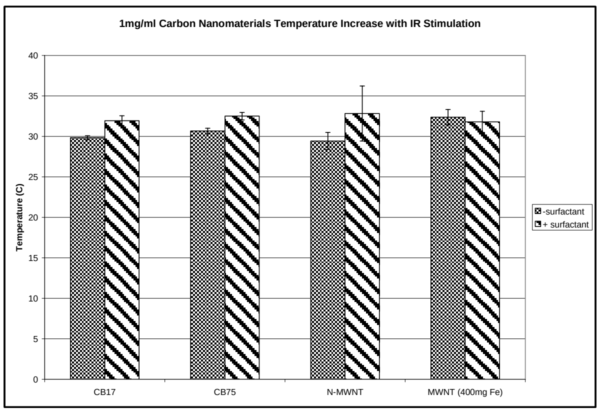
2 METHODS

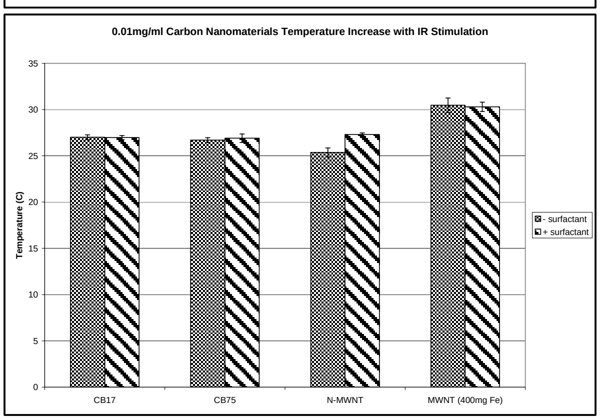
Two types of multi-wall nanotubes were employed. Carbon nanotubes grown with four hundred milligrams of iron were sonicated in concentrated acids for fifteen hours to shorten and clean the tubes. Consequently, this treatment adds carboxyl groups which aids in dispersion of the tubes in water without surfactant. Alternatively, nitrogen doped carbon nantoubes were used without any acid treatment. Dissociation of nanotubes for suspension in water was accomplished using a biocompatible Pluronic surfactant to create micelles around the tubes. Sonication aided in suspension of nanomaterials with and without surfactant. Two different diameters of carbon black (17nm and 75nm) were used at the same mass amount as the nanotubes. Pluronic was also added to some of the carbon black samples. Concentrations of 1mg/ml, 0.1mg/ml, and 0.01mg/ml of the carbon nanomaterials were used with a 1% weight solution of the surfactant.

Five hundred microliters of the carbon nanomaterials solutions was place in a dish having the same diameter as the incident laser beam.A 1064nm continuous wave fiber laser was used for infrared stimulation at a power of 2W. The laser source was applied for fifteen seconds approximately 2cm away form the sample. Following laser heating, nanotubes were observed by transmission electron microscopy to verify that the tubes were still wrapped with Pluronic.

3 RESULTS

From figures 1 and 2, it is evident that the cut, cleaned and undoped nanotubes give the highest temperature increase. However, in the carbon black samples at higher concentration, once the surfactant was added and better solubility of the material occurred, the carbon black samples provide similar temperature increases as the nanotubes. The nitrogen doped nanotubes do not cause the same increases in temperature as the undoped tubes due to increased bundling. The doped tubes do as well as the undoped once the surfactant is added, showing the importance of debundling for heating efficiency.





Figures 1 and 2: Temperature increases for carbon black with diameters of 17nm or 75nm, nitrogen doped nanotubes (N-MWNT) and MWNT grown with a specified iron concentration. Each sample was subjected to laser application either with and without surfactant and the temperature increase was measured.

If the micelle encapsulating the nanotube is removed during heating then rebundling of the nanotubes is expected, which may be determined by electron microscopy and precipitation of the tubes in solution. See figure 3. This figure shows that the surfactant is removed following laser application. Upon standing after laser application the nanotubes tended to aggregate towards the center of the dish.

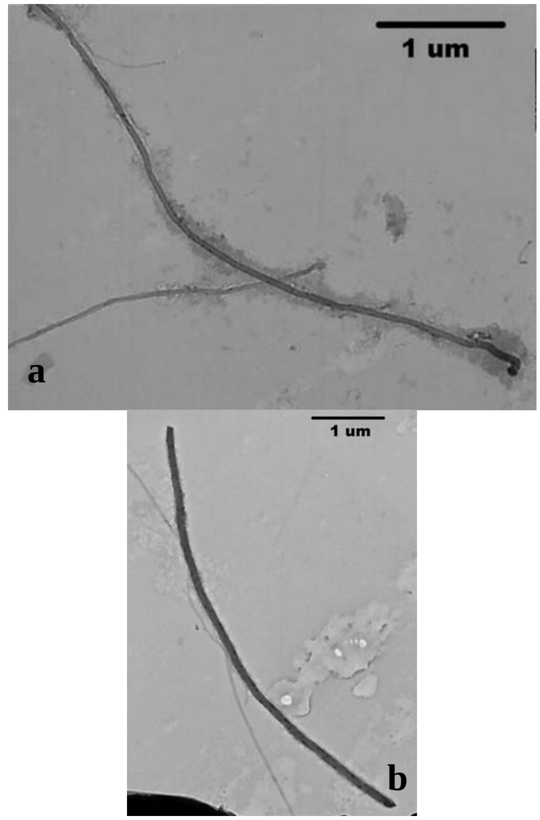


Figure 3: Multi-wall carbon nanotubes with Pluronic micelle before laser exposure (a), and after 4 minutes exposure to 3W, 1064nm wavelength (b). There is minimal Pluronic wrapped around the nanotube following laser exposure.

4 Conclusion

Although nanotubes may potentially be used as a therapeutic for localized heating *in vivo*, it is beneficial to determine if nanotubes really are more valuable for these applications than carbon black. Thus, a comparative analysis of the heat generated by nanotubes versus nano-sized carbon black has been completed to show how nanotube bundling affects the efficiency of nanotube heating. The results of this work indicate that carbon nanotubes must be debundled to heat more effectively than carbon black and that care must be taken to insure that nanotubes do not rebundle following laser application.

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