

# Development of a Biologically Enhanced Carbon Nanotube Based Composites

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## ABSTRACT

Composite materials continue to be important to the evolution of human space flight activity. The low weight/high strength ratio and thermal properties of carbon based composite materials in particular that make them well suited for use in extraterrestrial environments is widely known and understood. Much of the recent activity in carbon composite investigations relevant to space flight has focused on the potential of materials incorporating carbon nanotubes (CNTs) for enhancing mechanical, electronic and radiation attenuating properties of aerospace materials. We describe a CNT based, biologically enhanced composite that provides simultaneous functionality across all three of the aforementioned properties. Initial studies show that a mixture of biological polymers and CNTs will increase shielding radiation capability and provide a host of other functional properties. Additionally, it has been shown that the biological polymer can be modified and tuned to respond to different types of radiation.

**Keywords:** organic polymers, biological polymers, carbon nanotubes, multifunctional materials, composite materials

## 1 INTRODUCTION

High performance composites are currently being used in the marine, automotive, aerospace and defense industries. These industries demand materials with properties that are similar or better than conventional metals at a fraction of the weight. Advanced composite materials can meet these demands. Advanced composite materials are carbon or aramid fiber-based composites, metal matrix composites (MMC), ceramic matrix composites (CMC) and carbon-carbon (C-C) composites, which can be used to replace metal materials for structural applications [1]. However, there are still some weakness with advanced composites, such as the transverse properties, low toughness and high environmental sensitivity, which are mainly determined by the properties of the resin matrix. This proposed research will focus on using advanced composites, mainly biological polymers, along with nanoparticles to produce multifunctional

composites, with enhanced material properties, for the development of value added material applications.

The development of biologically reinforced nanocomposites is presently one of the most promising areas in materials science and engineering. The exceptional properties of nanoparticles have made them a focus of widespread research. Carbon nanotubes and other nanoparticles have the potential to greatly enhance the properties of composites when combined with biological polymers which were previously unobtainable properties can be developed [2]. Moreover, the biological polymer can be tuned through chemical modification. Using nanotubes in biologically enhanced composites provides the potential for improving resin-dominated properties, such as interlaminar strength, toughness, thermal and environmental durability. As an example, biological polymers are capable of convert radiation into electrical energy which can be later used via trickle charging. Consequently, whereas most resins would degrade via radiation over time, the biological substance would mediate such phenomena.

By combining nanoparticles with biological polymers for reinforcement, enhanced functionality composites can be produced, with superior properties to that of regular composites. In order to successfully produce multifunctional composites several problems must first be understood. (1) Dispersion of nanoparticles is a major concern due to the challenges that exist with the formation of agglomerates during the mixing of nanoparticles with the resin matrix. (2) With the addition of nanoparticles to the resin matrix there is a dramatic increase in the viscosity of the resin. This poses a problem with the processing of nanocomposites. (3) The effects of nanoparticles on the properties of the resin matrix system need to be fully evaluated and understood.

## 2 PREPARATION OF SAMPLES

Two samples were used to evaluate the performance and properties. One is a modified form of buckypaper. Biological polymer is added to the initial CNT, surfactant and water mixture. The resulting mixture is sonicated and the paper is formed through filtration. The other sample preparation technique was to produce the aforementioned

mixture with basic commercial grade gelatin (no sugar, no coloring). The resulting mixture was sonicated and cooled to gel.

A factorial design was established which included 1) magnetic alignment (0, 1, 3, & 5 Tesla in strength and 2) concentration of the biopolymer (none, low, high).

### 3 OBSERVATIONS & DISCUSSION

The CNT based gel had a fairly homogenous distribution of CNT which was accomplished primarily through locking the CNT into place after sonication via the rapid set of gelation. That is, the onset of gelation was quickened as a consequence of the presence of the CNT. The CNT based gel coagulated within 90 seconds whereas the non-CNT system took several hours to coagulate in a 9°C refrigerator. The system's gel time with and without CNT did not change from with the addition of the biological polymer. That is, with CNT it took less than 90 seconds to gel and hours otherwise. Another important noteworthy phenomena was the resulting tenacity of the system upon gelation. Figure 1 shows a beaker of the CNT based gel which was held upside down for over 1.5 hours.



Figure 1: CNT based gel maintains its temperature and surface tension after 1.5 hours upside down

In addition, the in-situ CNT based gel system has attractive mechanical properties, magnetic alignment and biological enhancement seem to have increased the CNT based system. Table 1 shows that magnetism increases, the electrical resistivity of a system.

In Table 1, the y axis is computed by taking the ratio of the resistance perpendicular to the direction of the applied magnetic field to the resistance parallel to the direction of the applied magnetic field.

The analysis performed in Figure 2 was for a suspension using 40mg of CNT for a 1 liter solution. This solution was modified by reducing the volume of CNT by 80% and replacing it with biological polymer under 3 Tesla. The resulting electrical resistivity anisotropy ratio was calculated to be slight greater than 4. It is believed that the biological polymer allows for greater communication between CNT molecules thus showing lower resistivity in the aligned direction.

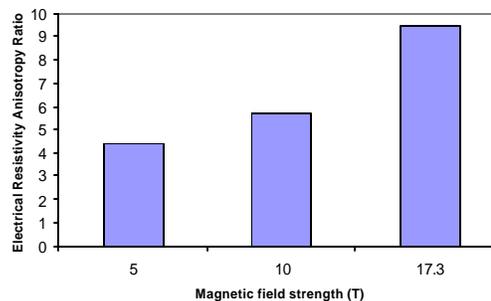


Figure 2: Impact of Magnetic field strength.

From the electrical resistivity and from Fig 3, it is clear that the molecular architecture of magnetically aligned CNTs is demonstrably different than randomly CNT in a buckypaper composite.

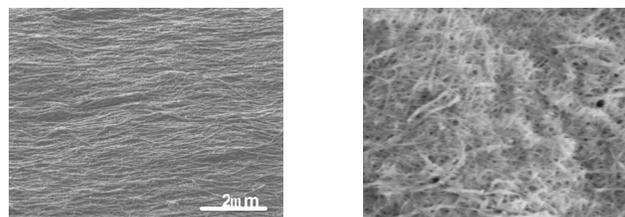


Figure 3: Visual Affect of 5 Tesla on buckypaper (left side is of magnetically aligned system where the right side is not aligned)

The biological polymer chosen is currently FAMU proprietary; however it's structure is chemical similar to Figure 4. The polymer has a series of conjugated bonds which allow for electron migration, thus conductivity. The polymer is a semiconductor. Once doped, the biological polymer conductivity was measured at  $10^{-2} - 10^{-3}$  Sm/cm.

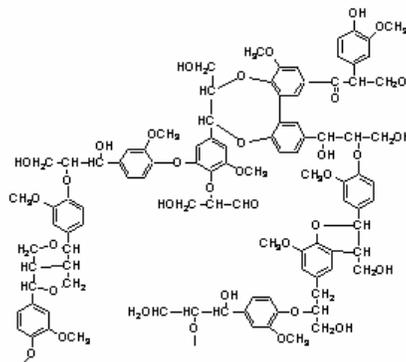


Figure 4: Proposed Conductive Biological Polymer

Other properties were measured from this biological polymer. These are that a 2 cm<sup>2</sup> panel of the system was capable of an observable photoconductivity (~0.656 V).

The sizeable photoconductivity observed is hypothesized to be born from its color as seen in Figure 5.



Figure 5: Brownish-Black colored biopolymer in powder form

The system seemed to persist at the same voltage which demonstrated that the system had capacitance. Specifically, the system was able to maintain a voltage of > 0.6 V over 30-40 minutes. Figures 6 & 7 show the semi-conducting nature of the systems which is thought to have aided the resistivity of the aligned CNT/biological polymer system.

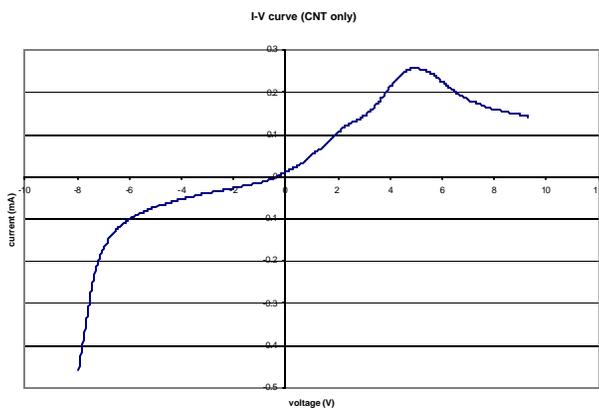


Figure 6: I-V curve of CNT only based gel

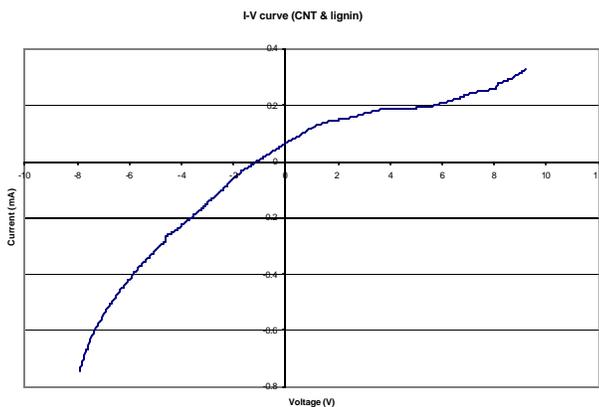


Figure 7: I-V curve of CNT with lignin based gel

A 10 micron sample was able to block 20% of beta radiation. Consequently, a radiological study was performed which calculated the radiation stopping power

for the proposed materials. This calculation estimated the energy transferred to the material which may result in ionization of atoms, displacement of atoms and/or generation of secondary radiation (pair – production, etc...). Equation 1 is the Bethe-Bloch equation that allows us to determine the radiation energy transfer per unit length of an element. Equation 2, the Bragg Additivity formula, allows us to calculate the radiation energy deposition per unit length of the material. This is done by using the stoichiometry of the molecule being modeled. Polyethylene (or polyethene) has been defined as a benchmark for radiation blocking due to its high concentration of protons. For polyethene, the relative stoichiometry is C (1) H (2). That is on average, there are two hydrogen atoms for every carbon atom. From these equations, figures 8-10 were created. Figure 8 shows the stopping power of both the targeted biopolymer and CNT in the presence of alpha particle radiation. Figure 9 is for beta particle radiation, and figure 10 is for proton radiation.

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A\beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} \right] \quad \text{Equation 1}$$

$$\frac{dE}{dx} = \sum w_j \left. \frac{dE}{dx} \right|_j \quad \text{Equation 2}$$

From this level of analysis, it seems as though the biopolymer composite has radiation stopping power comparable to that of polyethylene. Additionally, the biopolymer differences in the atomic composition provide some differences. One of these might be the level of saturation in the bonds and benzyl structures that exist in the proposed biological polymers. These structures might allow for increased stability, especially if the molecule is capable of distributing some of the radiation energy when bonded to CNTs.

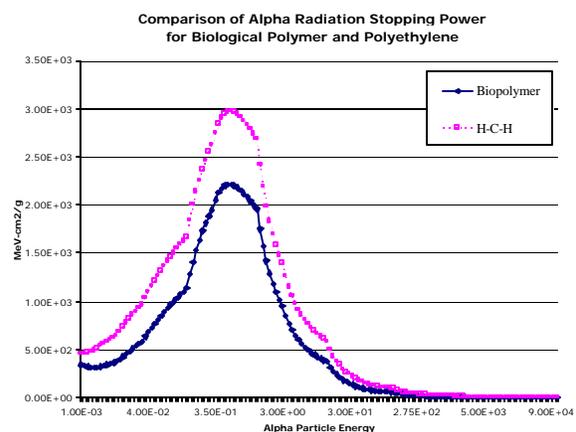


Figure 8: Comparative study of Alpha Radiation Stopping Power of the Proposed Biological Polymer and Polyethylene

## 5 FUTURE STEPS

Much work is required to fully develop, fabricate and characterize these biologically enhanced CNT nanocomposites. A technology platform to develop will be required. From these platforms, devices and applications can be built and tested. The promise of new electronic materials, energy systems and radiological materials can be achieved with further study.

## REFERENCES

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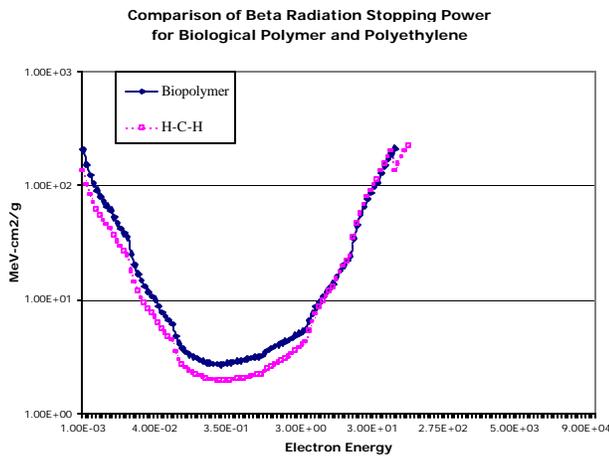


Figure 9: Comparative study of Beta Radiation Stopping Power of the Proposed Biological Polymer and Polyethylene

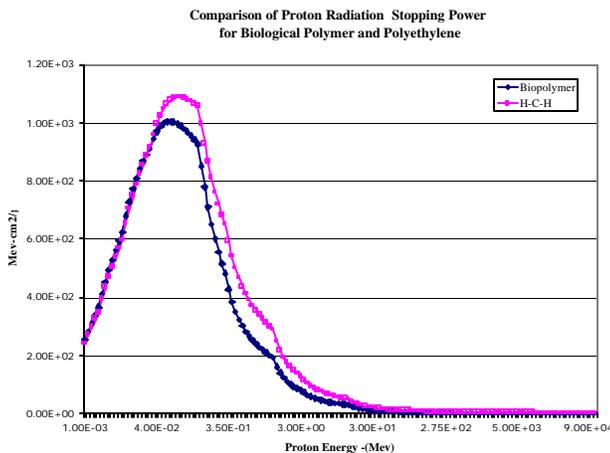


Figure 10: Comparative study of Proton Radiation Stopping Power of the Proposed Biological Polymer and Polyethylene

## 4 CONCLUSIONS

Biological polymer can greatly enhance the mechanical, electrical, optical and radiological properties of CNT based nano-composites. In the present study, it is shown that smaller concentrations of CNT can be used in the presence of biological polymers while simultaneously achieving similar properties using less energy and costs. Additionally, it is known that CNTs have an enormous unlocked mechanical strength. From these initial studies, the biological polymers seem to have the ability to help achieve some of these through polymer-tube entanglement. Lastly, the radiological properties for this system seem to be most interesting and should have great merit for interstellar travel.