Aerospace Applications of Carbon Nanotube Materials

Mark W. Schauer[1], David Gailus[1], and Meghann A. White[1]

[1]Nanocomp Technologies, 57 Daniel Webster Highway, Merrimack, NH 03054, U.S.A.

ABSTRACT

The use of floating catalyst chemical vapor deposition to make carbon nanotube (CNT) materials for aerospace structures overcomes the need for dispersants, and allows for products that consist mostly of nanotubes. CNT-based material is currently deployed in Space for Electrostatic Discharge and Electromagnetic Interference (ESD/EMI) shielding devices. Products for other applications, including coaxial cables and honey-comb core structures are in qualification. Applications such as heaters and composite pressure vessels are in development. Initially products are being developed for space applications, since they represent the highest valued products, however, it is expected that cost reductions from current production scale-up efforts will result in this technology being able to address the broader aerospace market in the future.

Keywords: carbon, nanotube, aerospace, composite

INTRODUCTION

Recent work in scaling-up production of carbon nanotube (CNT) yarns, tapes and sheets is making these materials available to a wider audience. While bulk materials made with CNTs have still not attained the properties seen in individual nanotubes[i], the macroscopic materials produced by floating catalyst chemical vapor deposition (FC-CVD) have the strength and electrical conductivity necessary for many applications. These materials have already been used in space applications, such as EMI shielding and structural panels, as well as wires and cables. With ongoing and planned production expansion, these materials will soon be available to the broader aerospace community for applications proven in space, as well as other products for the terrestrial flight market.

The CNTs from an FC-CVD furnace can be collected on a rotating and translating drum to produce a large-format (~ 1.3 m x 2.4 m) sheet of material that can be integrated into a variety of products. CNT sheets made by direct collection from FC-CVD are much stronger and more electrically conductive than analogous material made from CNT powders using paper-making technology ("buckypaper")[ii]. CNT sheets from FC-CVD can be infiltrated with polymers resulting in composites with higher levels of CNT loading than is possible using the standard approach of integrating powdered CNTs into polymer manufacturing processes. Different polymers can be used for specific applications of interest to the aerospace industry, such as structural panels[iii], electromagnetic shielding[iv], and heaters.

CNT yarns can be made by direct spinning of FC-CVD material[v]. Instead of collecting the CNT material on a drum to form a sheet, the material can be directly collected into a roving or tow. This roving can be spun into a yarn and then plied, braided or woven into a final form factor. The roving can be chemically stretched and densified into a yarn with enhanced strength and electrical conductivity before being manufactured into final form, such as the core conductor of a data cable[vi]. The superior strength, fatigue resistance, reduced inertia and resistance to salt water degradation makes this yarn material ideal as an arresting cable on aircraft carriers.

Tapes of various widths, from 0.5 cm to 10 cm can be produced in ways analogous to yarn formation. These can be processed, and used to form the shielding in a coaxial cable or shielded data cable[vii]. Cables using CNT material in the outer sheath, or both the core conductor and sheath, have been produced for data transmission on aerospace vehicles.

EMI SHIELDING

Sheets of Nanocomp material have been evaluated by a number of cable manufacturers for their EMI shielding effectiveness. These studies have shown that CNT sheet material can be as effective as metallic shielding at a fraction of the weight (see figure 1). Because of this proven effectiveness as EMI/ESD shielding components made from Nanocomp CNT sheets are currently on the NASA JUNO project on their way to Jupiter.

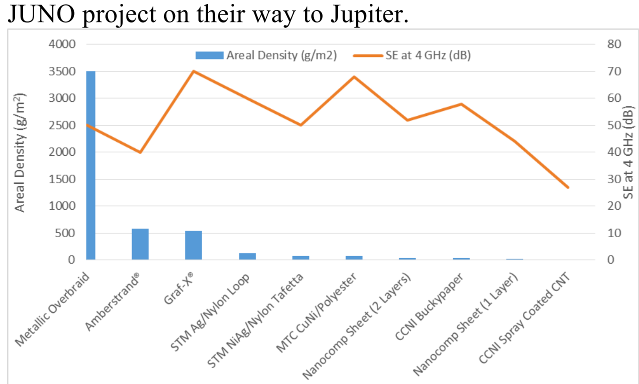

Figure 1: Data showing that 2 sheets of CNT material provides as much shielding as metallic over-braid at a fraction of the weight.

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WIRE AND CABLES

Prototype coaxial cables have been produced using CNT material for both the core conductor and the sheath. Of the two conducting components the sheath represents a greater

Figure 2: CNT tape being wire-wrapped around a core conductor and insulator.

weight savings by replacing the metal with CNT material. In conjunction with collaborators in the wire and cable industry we have successfully integrated CNT tape material into their wire-wrapping system (see Figure 2). The resulting data transmission cables performed successfully in tests, and represented a significant weight savings compared to standard cables. Cables have also been produced using plied CNT yarn material as the core conductor. These cables also passed data transmission tests, but are limited in length due to the lower electrical conductivity of the CNT material relative to copper. Work is ongoing to improve the CNT electrical conductivity in order to increase the maximum working length of data transmission cables.

HEATERS

The unique properties of Nanocomp CNT material make it ideal in a variety of heater applications of interest to the aerospace industry. The flexibility and thin form factor

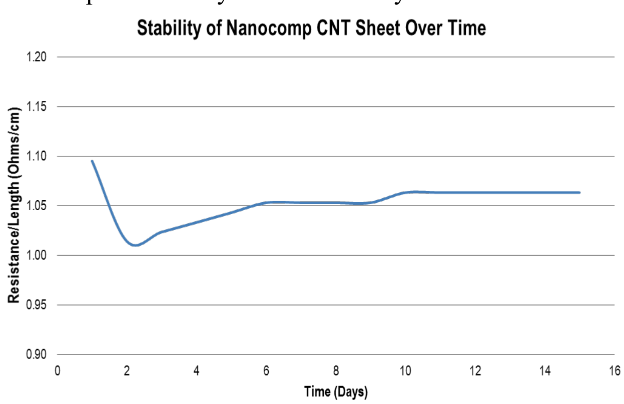

Figure 3: Resistance as a function of time for a CNT Sheet heater. After an initial "breaking in" period, the performance is stable with time.

make applications such as wing de-icing possible. Because the material is a continuous sheet, punctures will not affect performance in the same way a broken wire would in current wire based heater technologies. Initial studies have shown that after an initial breaking-in period, heater performance is stable (see figure 3). This flexible, durable, chemically inert material can be produced in virtually unlimited form factors, and can find a place in a variety of aerospace heating applications.

STRUCTURAL COMPONENTS

Composites made by dispersing CNT powders and incorporating the dispersion into polymers can only achieve a few percent CNT loading, with very little enhancement of the polymer performance. By starting with a pure CNT

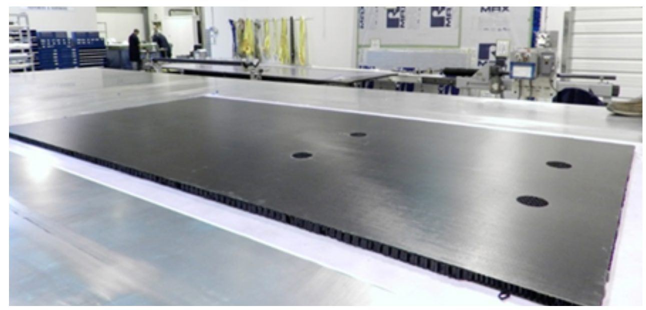

Figure 4: Honeycomb core made of Nanocomp CNT tape material with an aerospace polymer for stiffness. The core is covered with carbon fiber sheets top and bottom.

Nanocomp material and infiltrating the desired amount of polymer, much higher CNT loadings can be achieved. In this way composites can be produced that have the tensile strength and stiffness necessary for structural components in aerospace vehicles. Honeycomb core panels produced using Nanocomp sheet composites in the core are currently in qualification for use in space vehicles (see figure 4). Other form factors can be produced for different aerospace components.

CONCLUSION

The properties of bulk CNT materials formed from floating catalyst chemical vapor deposition are adequate for many aerospace applications, and can lead to significant weight savings. To realize these applications the collection and post-production treatment processes must be tailored to the specific applications. For EMI shielding a light binder (~1%) polymer is adequate. For wire and cable applications yarn and tape formats with chemical processing to further enhance strength and electrical conductivity are needed. For core conductors chemical stretching and cleaning may be needed, while the grounding sheath may need minimally processed tape. For heater applications thermal resistance may need to be enhanced with additives. For structural panels high loadings (20%-50%) of high strength polymer is appropriate. With a wide range of form factors and processing systems CNT materials can find a variety of applications in the aerospace industry.

REFERENCES

[i] B.G. Demczyk, Y.M. Wang, J. Cumings, M. Hetman, W. Han, A. Zettl, R.O. Ritchie *Materials Science and Engineering:A* **334** 173-178 (2002). doi:10.1016/S0921-5093(01)01807-X

[ii] Raymond L. D. Whitby, Takahiro Fukuda, Toru Meakawa, Stuart L. James, Sergey V. Mikhalovsky *Carbon* 46 (2008) 949-956. doi:10.1016/j.carbon.2008.02.028

[iii] Xiefei Zhang, Qingwen Li, Terry G. Holesinger, Paul N. Arndt, Jianyu Huang, P. Douglas Kirven, Timothy G. Clapp, Raymond F. DePaula, Xiazhou Liao, Yonghao Zhao, Lianxi Zheng, Dean E. Peterson, and Yuntian Zhu *Adv. Mater.* **19**, 4198–4201(2007). doi: 10.1002/adma.200700776

[iv] Yonglai Yang, Mool C. Gupta, Kenneth L. Dudley and Roland W. Lawrence *Nano Lett.*, **5** 2131–2134 (2005). doi: 10.1021/nl051375r

[v] Tsu-Wei Chou, Limin Gao, Erik T. Thostenson, Zuoguang Zhang, Joon-Hyung Byun *Composites Science and Technology* **70,** 1–19 (2010). doi:10.1016/j.compscitech.2009.10.004

[vi] Jennifer Mann, David S. Lashmore, Brian White, and Peter L. Antoinette “Carbon nanotube-based coaxial electrical cables and wiring harness” US Patent 8,847,074, filed May 7, 2009, and issued September 30, 2014.

[vii] Harvey, Stefanie E. (2013) *Carbon as Conductor: A Pragmatic View*, Proceedings of the 61st IWCS Conference, International Wire & Cable Symposium (pp. 558-562).