# CNT Composites for Aerospace Applications

S Bellucci[1], C Balasubramanian[1,2], P Borin[1,3], F Micciulla[1,3], G Rinaldi[4]

[1] INFN-Laboratori Nazionali di Frascati, Via E. Fermi 40, 00044 Frascati, Italy
[2] Department of Environmental, Occupational and Social Medicine, University of Rome Tor Vergata, Via Montpellier 1, I-00133 Rome, Italy
[3] University of Rome "La Sapienza", Department of Aerospace and Astronautics Engineering Via Eudossiana 18, 00184 Roma, Italy
[4] University of Rome "La Sapienza", Department of Chemical Engineering and Materials, Via Eudossiana 18, 00184 Roma, Italy
bellucci@lnf.infn.it, bala@lnf.infn.it, borin@pd.astro.it, starfederico@inwind.it, gilberto.rinaldi@ingchim.ing.uniroma1.it

## ABSTRACT

Carbon nanotubes were synthesized by thermal arc plasma process after optimization of the synthesis parameters. These samples were then analysed by Scanning and Transmission electron microscopes (SEM and TEM), in order to establish the morphology of the nanostructures. Atomic Force Microscopy (AFM) and Electron diffraction studies were also carried out before using the sample for the composite material preparation. Composites of epoxy resin with curing agent as well as a mixture of graphite and carbon nanotubes were prepared with varying proportions of the mixture. The electrical resistivity of the material was studied under varying pressure and voltage conditions. Preliminary results of these studies present interesting features which are reported here.

## 1. INTRODUCTION

The study of nanotubes has advanced tremendously in a relatively short span since its first discovery in 1991 by Iijima [1]. The properties of these nanostructures are so unique and enhanced that it is finding applications in various spheres of life – right from bio-medical to optical and to space applications [2-12].

Essentially two families of carbon nanotubes exist: SWNT or (single wall nanotubes), that are constituted by only one rectilinear tubular unity and the other MWNT (multi wall nanotubes}, that are constituted by a series of coaxial SWNT. Though generally both the types have high aspect ratio, high tensile strength, low mass density, etc. the actual values could vary depending on whether it is SWNT or MWNT. Of the two types SWNT is better suited for mechanical applications.

Owing to their exceptional morphological characteristics, electric, thermal and mechanical, carbon nanotubes yield a material particularly promising as reinforcement in the composite materials with metallic matrixes, ceramics and polymers.

The key factor in preparing a good composite rests on good dispersion of the nanotubes, the control of the bonding between nanotubes and matrix, the density of the composite material [2]. Besides, the type of nanotubes (SWNT, MWNT) the synthesis mode (arc discharge, laser, CVD) etc are important variables since they determine the perfection of the structure and the reactivity of the surface.

## 2. EXPERIMENT

Carbon nanotubes were synthesized in a DC arc plasma system in helium atmosphere at a pressure of 600 torr. Arc was struck between two electrodes consisting of a high purity graphite rod and a block of graphite. The discharge is typically carried out at a voltage of 20V and a current in the range of 80 – 100 A. Some amount of the evaporated carbon condenses on the tip of the cathode, forming a slag-like hard deposit. The deposit essentially in the cathode consists of bundles of carbon nanotubes mixed with small quantity of amorphous carbon.

The as-synthesised samples were characterized by means of SEM, TEM and AFM. Figures 1 and 2 show SEM images.

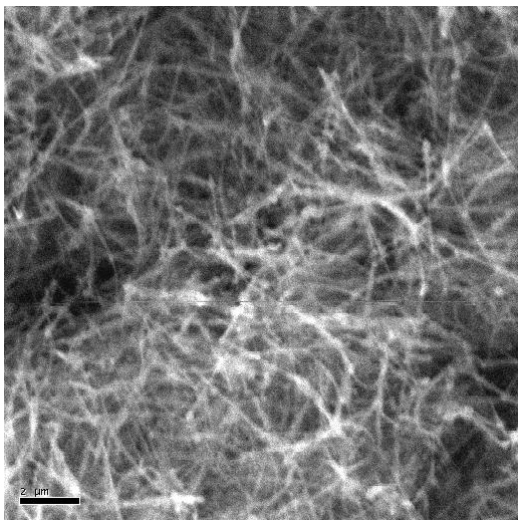


**Fig.1 :** SEM images of CNT with arc discharge.

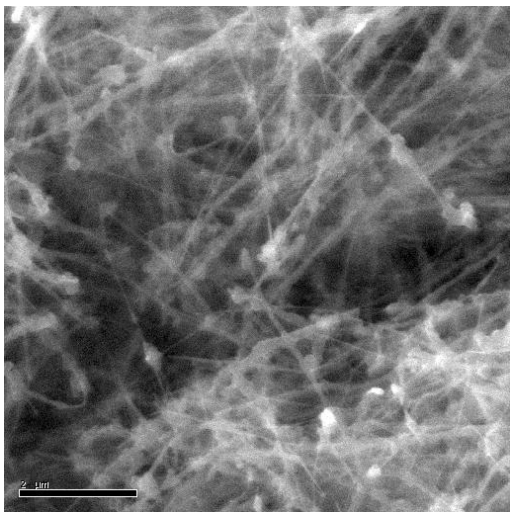


**Fig. 2:** SEM image of CNT which shows straight and long nanotubes

## 2.1 Nanotubes Composites

Due to the unique properties of carbon nanotubes they are being widely studied as a constituent of composite material. CNT based composite materials are increasingly being considered for mechanical, electrical and space applications. Even studies on biosensor composites based on functionalized nanotubes and nanoparticles are reported [9-12]. They are also being studied for the suitability and applications in aerospace and aeronautical fields. A prospective application in aerospace that we are studying is the improvement of electrical properties of composites made from carbon nanotubes and epoxy resin [13-15]. To start with it was decided to mix the epoxy resin with graphite. The purpose was to make a light, thin and mechanically strong composite material to cover electric circuits against external electromagnetic interference. This is very important for air and space crafts.

The epoxy resin that was used is a commercial Shell product Epon 828. Two types of curing agent were used along with the resin; mainly A1 curing agent and PAP8 agent. Also some of the resin+curing agent samples were mixed with 20 wt% of graphite and these were used for the analysis of the electrical resistivity studies. We stress that the first curing agent possesses polar groups in its chemical composition, whereas the second agent contains benzene groups. As a consequence, the mechanical properties of composites where the PAP8 agent has been used turn out to be improved [16]. However, the stability of the mechanical properties, under varying pressure conditions, as well as the corresponding resistivity behavior, has not been investigated yet. In the present work, we fill up this gap, in the part concerning the electrical transport properties.

The composite was made by manually mixing the micron sized (particle size ~ 20 microns) graphite powder in the resin+curing agent. Care was taken to avoid air bubbles in the mixture. The experiments were performed in two stages : Initially two types of resin with curing agents were used to find the one most suitable for the earlier defined applications. In the second stage this resin was mixed along with the CNT to study the change/ enhancement of the electrical property.

In order to comply with the standard specification of the U.S. military authorities, we tested the electrical properties of the composite materials, making use of "Y" shaped electrical circuits having two parallel lines as the tail of the "Y" with 1 mm gap between them and a length of about 2.5 cms. The circuits were made on a PC base with silver print and the two arms of the "Y" were connected to the picoammeter and the high voltage supply. The composite mixtures were spread, like thin films, on the circuit and electrical resistance tests were carried out using Keithley 6485 Picoammeter with short circuit protection.

The current through the sample was recorded for three different applied DC voltages, namely – 200, 500 and 1000 V. The resistance and the resistivity were then calculated. The experiment was repeated under three different pressures – atmospheric, $10^{-2}$ and $10^{-6}$ mbar. The low pressure measurements gave indirectly the effect of moisture on the resistivity values of the samples. The

plots in figures 3, 4, 5 and 6 show the resistivity *vs* applied voltages for various samples under varying voltage and pressure conditions.

## 3. RESULTS AND DISCUSSION

### A. Studies with resin and graphite

Analysing the data it is observed that the resistivity of samples with curing agent A1 is found to be a few times lower than the samples with curing agent PAP8. It is important to note that the absolute change in resistivity is less over a wide voltage range of 200 to 1000 volts for the sample with A1 curing agent (as seen from figures 3 & 4), whereas for the sample with PAP8 curing agent the resistivity changes marginally more with increasing voltage.

Notice that the resistivity data were collected with the same samples at two different times of the year (i.e. July 2005 and September 2005), in order to have a rough estimate of the influence of climatic and environmental conditions on their performance. It appears, from a preliminary analysis of our data, that the stability of composites employing PAP8 agent is jeopardized by the addition of graphite. In the case of composites with A1 curing agent the behavior is quite opposite, i.e. the stability of the material increases as graphitic additions are included. This seems to favor the use of A1 curing agent from the point of view of the optimization of the aerospace applications sought for.

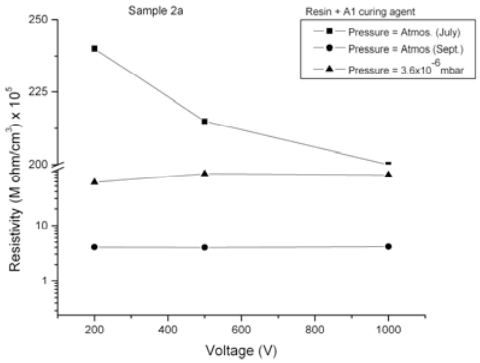



**Fig. 3:** Plot of resistivity vs. voltage for the sample Resin+A1 with no graphite added

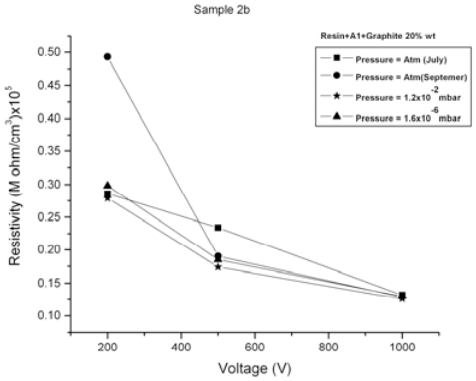



**Fig. 4:** Plot of resistivity vs. voltage for the sample Resin + A1+graphite added.

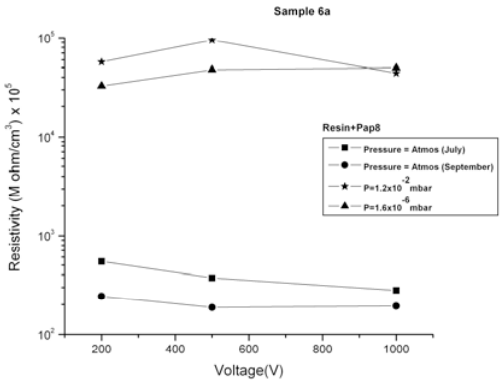



**Fig. 5:** Plot of resistivity vs. voltage for the sample Resin + PAP8

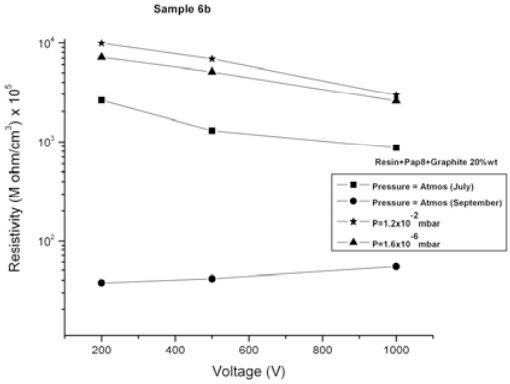



**Fig. 6:** Plot of resistivity vs. voltage for the sample Resin + PAP8 + graphite added

### 3.1 Variation of resistivity with pressure/humidity

It is expected that when the ambient pressure is decreased while doing the resistivity measurements the humidity also gets decreased resulting in higher resistivity values. The resisitivity values for all the samples show some variation when done in atmosphere as compared to when done in low pressure. However, this variation gets reduced when graphite is added to the resin.

From the plots above we observe that, for the first sample (i.e. sample with curing agent A1 – figures 3 and 4), when we work in different pressure conditions, the resistance changes very little Instead in the second sample, the resistance undergoes remarkable variations when we work in different pressure and humidity conditions, as seen in (figures 5 and 6). This feature might constitute a drawback for the use of the corresponding curing agent PAP8 for composite devices working under standard aerospace conditions, where the values of the pressure can undergo substantial variations.

### 3.2 Variation of resistivity with graphite addition

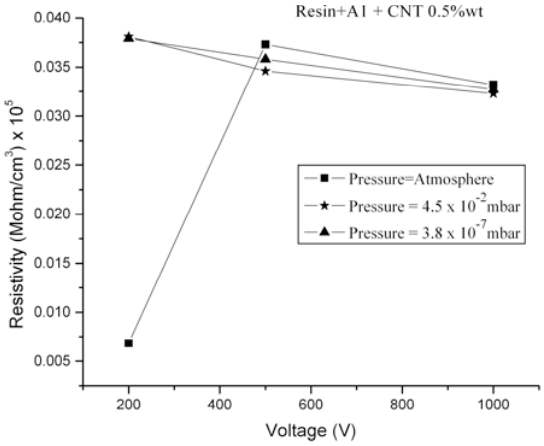
It is observed that the resistivity change is very large – near about 3 orders of magnitude when 20% graphite is added to the resin + A1 curing agent, whereas for the PAP8 curing agent the increase in resistivity due to addition of graphite is comparatively only marginal, of about 3 to 5 times.

These above results when considered in totality gives a broad spectrum wherein we find that the resin + A1 curing agent + graphite seems to be an ideal candidate for applications in various pressure ranges as well as voltage ranges. The Resin + A1 + graphite has the lowest changes in the resistivity values for voltages from 200 to 1000 V and also for a pressure difference of atmospheric to $10^{-6}$ mbar

## B. Studies of Resin with CNTs

Resistivity measurements were performed for composites with A1 resin in combination with carbon nanotubes (shown in Fig. 1). Composites were made replacing graphite with CNTs. The quantity of CNTs added was 0.5 wt% of the resin mixture. Figure 7 shows the plot of resistivity vs. voltage for this sample. As can be observed the resistivity values changes drastically with the addition of a small quantity of CNTs. The Resin A1 with no graphite or CNT has a resistivity in the range of few tens of M ohms ($\times 10^5$) /cm$^3$ whereas when 0.5 wt% of CNT is added the resistivity reduces by a factor of $10^3$ to values ranging from 0.01 to 0.04 Mohms ($\times 10^5$)/cm$^3$. Also when these values are compared with the composite of resin A1 with graphite (refer Fig. 4), we observe that the resistivity 20 wt% of graphite is ten times higher than the addition of a small fraction of CNT.

**Fig. 7 :** Plot of resistivity vs voltage for composites of Resin A1 with CNT




## 4. CONCLUSIONS

Resistivity studies were performed on the composite material made from a resin with different curing agents (namely A1 and PAP8). Comparison was also made of composite of graphite against composites made from carbon nanotubes. The results of these studies present interesting features which are useful in choosing the ideal composition and ratio of the composite material for use in shielding of electrical circuits of space vehicles from radiations of the outer space.

We can deduce that the PAP8 curing agent is very sensitive to the humidity variations over a long time period and cannot optimize the performance of the circuits. Instead the A1 curing agent in combination with 20 wt% graphite microparticles is not very sensitive to these variations and makes the behaviour of an electrical circuit more stable.

The same resing A1 when combined with carbon nanotubes, in place of graphite powder, yielded resistivity values which were orders of magnitude better than either with plain resin or with large quantity of graphite powder.

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