



Mechanical and Electrical Properties of Carbon Nanotube (CNT) Yarns

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Abstract

Copper is a heavy transition metal characterized by good conductivity but poor fatigue and corrosive behavior. Carbon nanotube yarns (CNT) have the potential to overcome these problems by offering substantial improvements in weight and fuel savings. Therefore, reducing the amount CO_2 in the atmosphere from the launch of much lighter spacecraft's and aircrafts, all without fatigue. Electrical conductors made of CNT yarn are immune to corrosion especially in chloride environments. The CNTs low density, coupled with the low power required for high speed data has already opened up a market with selected applications directed by spacecraft demands for light-weight cables, especially coaxial cables used with copper cores. However, most power transition applications, lightning protection, and some shielding applications require low frequency conductivity to be significantly improved before these shielding, power, and low frequency applications are feasible. Achievement of even 1/2 to 1/3 of coppers conductivity may be commercially useful. The goal of this project was to address those factors influencing electron transport within CNT yarns as well as maximizing the amount of frictional contact between the CNTs. It was thought that by increasing the number of contact spots the resistivity would decrease and wire strength would increase. Factors considered include: (1) defects within the tubes and yarns, (2) cleanliness of the CNT surfaces, and finally (3) doping by adding oxidizing or reducing agents to the wire. We found that cleaning was more important than defects.

Goal

1. Determine the factors that affect electrical conductivity in order to reach conductivities close to copper.
2. Determine the best method of increasing CNT strength.

1. Introduction

CNT yarns

- Highly conductive
- Lightweight
- Strength that exceeds steel
- When treated correctly can reach specific conductivities close to copper

Benefits of replacing copper with CNTs

- Large improvements in weight
- Fuel savings
- Less carbon dioxide in the atmosphere
- No fatigue
- No corrosion in marine environments

Factors affecting conductivity

- Alignment: addressed by processing
- Cleanliness (organics and debris): addressed by cleaning
- Defects: addressed by annealing, increased process temperatures, and fuel chemistries
- Contacts: (Schottky barriers)
- Number of charge carriers: addressed by doping

2. Methods

Six different samples of CNT yarns* were put under several experiments in order to determine the best method of increasing their electrical conductivity. Using a four-point probe (figure 1), the electrical properties of each sample were measured before and after each experiment.

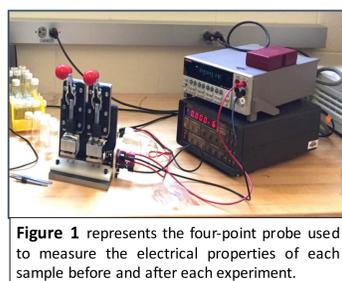


Figure 1 represents the four-point probe used to measure the electrical properties of each sample before and after each experiment.

(* supplied by Nanocomp)

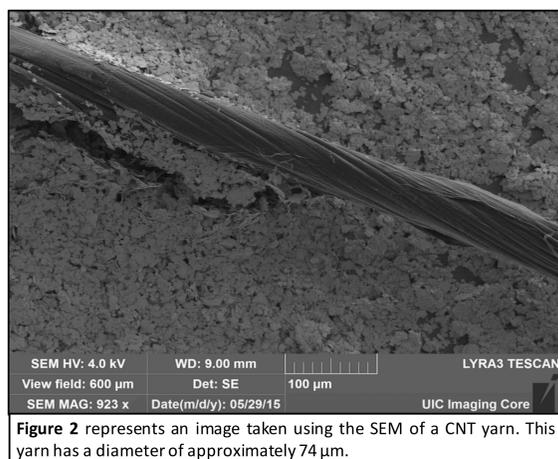


Figure 2 represents an image taken using the SEM of a CNT yarn. This yarn has a diameter of approximately 74 micrometers.

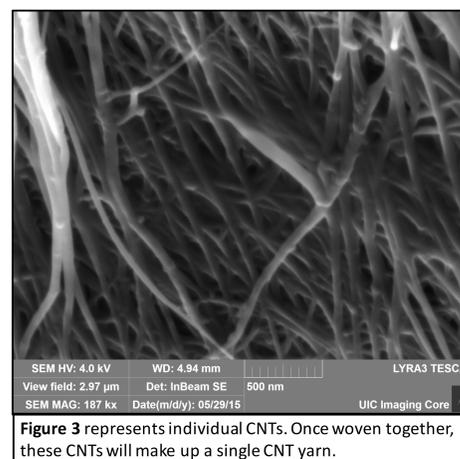


Figure 3 represents individual CNTs. Once woven together, these CNTs will make up a single CNT yarn.

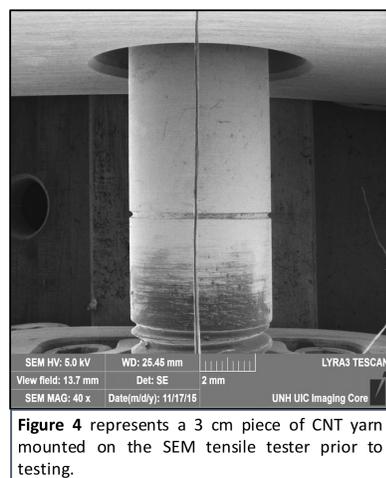


Figure 4 represents a 3 cm piece of CNT yarn mounted on the SEM tensile tester prior to testing.

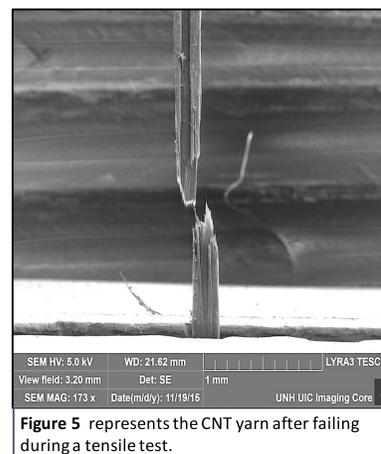


Figure 5 represents the CNT yarn after failing during a tensile test.

5. Applications

- Replace copper wire on aircrafts to reduce weight
- Replace copper wire in marine environments
- Reinforced concrete
- Dental implants

3. Experiments

Cleaning methods

Purpose: Remove organics and any debris left on the yarn.

Doping

Purpose: Increase the number of charge carriers.

Low temperature baking

Purpose: Removes any left over organics as well as annealing away defects.

High temperature baking

Purpose: Increases internal temperature of the yarn in order to anneal away defects.

High temperature baking with ethylene

Purpose: Ethylene will heal the defects present throughout the yarn.

Tensile testing

Purpose: Increase the strength of the CNT yarns using the best cleaning method.

4. Results

The best method of improving electrical conductivity was found during the doping experiments using 50% nitric acid (Figure 6). The purpose of using nitric acid was to help condense the material and hole dope in order to increase conductivity.

The next experiment that gave us good results was the methyl salicylate wash. The purpose of this cleaning method was to remove any left over residue from the samples.

Once the samples were soaked in methyl salicylate, they were able to be stretched. This resulted in a yarn of smaller diameter and an increased amount of friction between the CNTs. This increased amount of friction would ideally result in a stronger yarn (Figure 7).

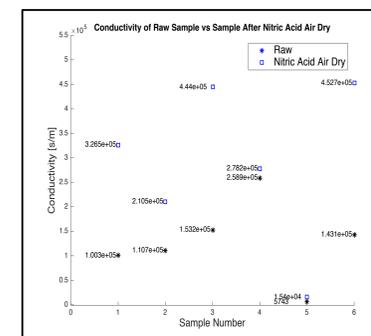


Figure 6 represents the effect nitric acid has on the conductivity of six different samples of CNT yarns.

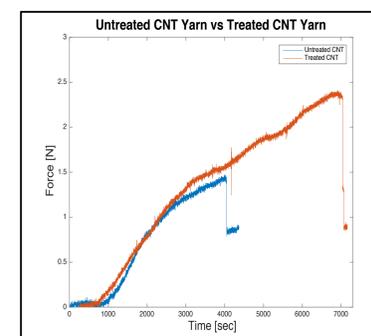


Figure 7 represents the change in strength between an untreated CNT yarn versus a treated CNT yarn. Treating the CNT yarn with methyl salicylate proved to increase the strength compared with an untreated CNT.