Project # 3: **"Nanostructured Composite Materials" (Composite Project)**

RET Participants:	Mr. Michael Day, Reading High School, Ohio and Ms. Sarah Woodward, Woodward Career Tech High School, Cincinnati, Ohio.
Faculty Mentor:	Dr. Jandro L. Abot, Assistant Professor, Department of Aerospace Engineering, , University of Cincinnati.
Graduate Student Mentor:	Mr. Yi Song, M.S. student, Department of Aerospace Engineering, University of Cincinnati.

Goals and Objectives

Non-destructive evaluation (NDE) methods like ultrasound, laser vibrometry, C-Scan, X-ray, eddy current, or thermal wave imaging could detect the presence of hidden damage like corrosion, inner layer cracks, inner layer delaminations, and fatigue fractures. Many approaches for in-situ structural health monitoring (SHM) have also been proposed in the literature to provide more frequent monitoring for damage. The methods include vibration analysis, fiber-optic strain measurement, and stress wave propagation techniques. These techniques for in-situ SHM are not cost-effective for application to large structures, which have complex geometry and high feature density. Carbon nanotube, carbon nanotube thread and other carbon nanostructured materials constitute a new approach for sensing that can make SHM practical. Dr Jandro Abot, the Faculty Mentor for this project, and his research group are are using carbon nanotube thread for sensing strain and damage in composite structures. The main advantages of CNT thread sensors are their small size, which allows embedding into the structure without altering the strain and stress distribution that are being measured. The goals for the teachers of this project are: (1) to learn about composite materials; (2) understand how carbon nanotubes can help in self-sensing composite materials; and (3) follow a research principle from beginning to end. The objective of the project is to evaluate the ability of carbon nanotube threads to monitor the state of strain in composite material

Equipment, Methods and Experimental Procedures

The methodology and experimental procedures for the project were broken down into these categories:

- Characterization of thread
- Fabrication of self-sensing composites
- Mechanical and electrical characterization of self-sensing composites
- Data collection and analysis
- Sensor calibration: calculation of gage factor

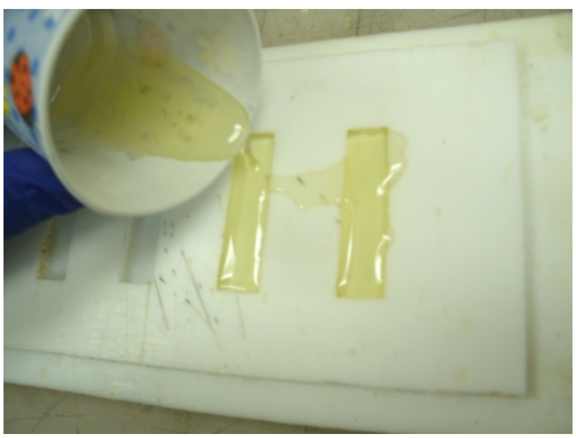
The characterization of thread required the teachers to take CNT thread and place it on a silicon sheet and stretch it so that a sample can be made from a polymer mix. A conductive epoxy holds the thread to the silicon sheet. Before casting the sample, the resistance is measured with a voltmeter and its length from the end epoxy points. Then the epoxied thread is slid under the microscope to find its diameter. All these measurement are used in calculations and photographs shown in Figure 1 shows the participants performing these measurements.

Test that resistance!!!!

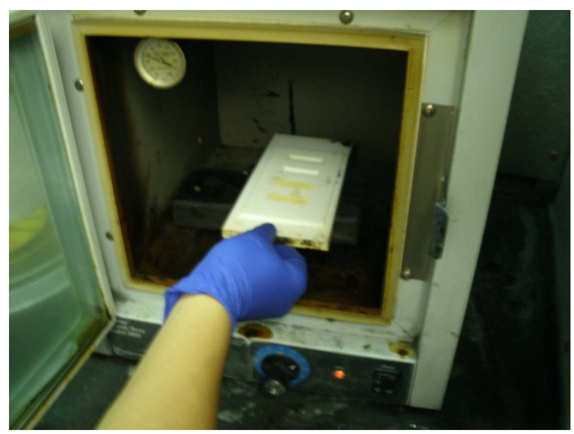
Those CNT threads are small!!!!

Figure 1. RET Participants Measuring Input Data

Fabrication of the self-sensing polymer composite requires mixing 100 parts of a resin with 90 parts of a hardening agent and 1 part catalyst. Making sure this mixture will not have any air bubbles when it hardens requires 2-3 hours of de-gassing it in the vacuum chamber. After pouring this mixture in to the molds with the CNT threads, it is placed in a vacuum oven for another 4-5 hours. After coming out of the oven, we measure its length, width, and height. Measuring the resistance is also done to make sure the CNT threads survived the mixing and heat. Finally the samples are ready for the load test. Photographs in Figure 2 show the different stages of the fabrication.



Pouring the polymer into the mold!

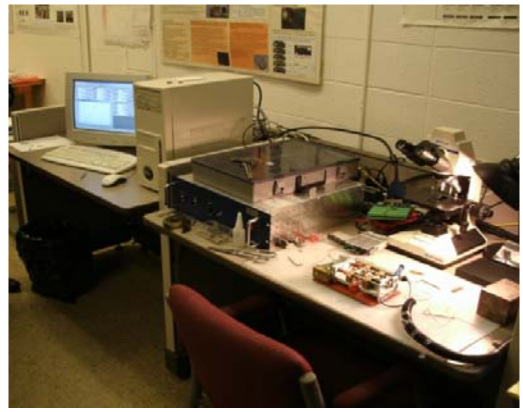


Heating and vacuuming the sample!

Figure 2. Fabricating the Self-Sensing Polymer Composite

Before placing the sample in the loading chamber for the mechanical characterization, the likely maximum load to be resisted must be calculated from existing theory for a 4-point bending test. The load was increased gradually from zero to the maximum value, and then unloaded back to zero. The participants were given the formula for the maximum load calculation, which is a function of the width and height of the sample, the lengths of the 4-points, and the maximum stress reached. To test the electrical characterization of the sample, from the CNT threads, the ends of the threads that were epoxied to exterior conductive wires are hooked to the high speed USB carrier. Once the loading process was started the data was recorded, processed and displayed in the computer connected to the data acquisition system. The load was controlled by the software MTEST and the resistance was recorded and displayed by Labview. These programs record and display in real time the change in the resistance of the threads as the load is being applied to the sample. Photographs in Figure 3 show the equipment used and the experiment in progress.

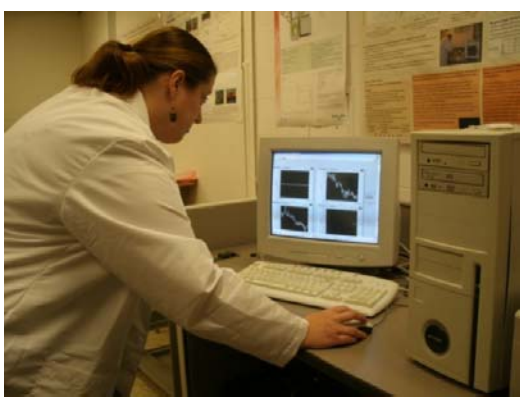
Get ready for some 4-point bending!!!!!



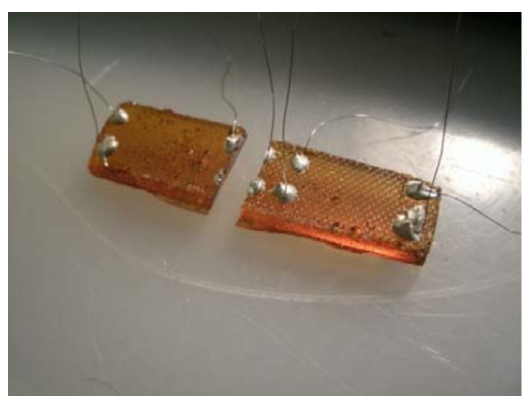
The equipment that makes it all happen!!!

Figure 3. Experimental Set-Up Used

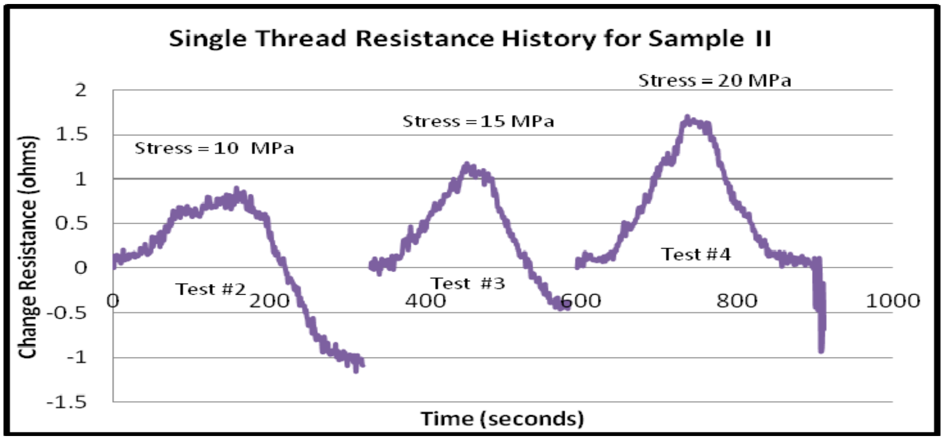
Highlights of the Research Findings: The load and the resistance data collected was organized and analyzed by the participants. One of the first things they did was to calculate the strain produced in the sample. Strain is directly proportional to stress and the constant of proportionality is the modulus of elasticity of the sample. Using this relationship, from the test data recorded the participants were able to evaluate the ability of carbon nanotube threads to monitor the state of strain in composite material. The data indicates that the resistance of the CNT threads and the strain ARE related! The participants also found that the more one stresses the CNT threads, the more sensitive they become. If more load was added to certain samples, their resistance increased. The participants determined the gage factor for their samples. Photographs in Figure 4 show the participants engaged in data analysis and interpretation.



Data, Data, Data, isn't it beautiful?



Failed sample!!!!!!



Data plotted as a graph

Figure 4. Data Analysis and Interpretation

It was concluded that CNT threads can monitor the state of strain in composite materials. Another highlight for the teachers was being able to see research from beginning to end at a major university, and planning how to take this experience back to their schools.

<u>Plans for Classroom Implementation</u>

<u>Mathematics Lesson for Pre-Calculus</u>: A three-day lesson plan was developed, which is presented below:

Day 1:

<u>Engage</u>: Teacher will perform an experiment using PVC pipe, and weights which should peak students interest about variables that correlate. The teachers will use the weights to bend the pipe. This will show a correlation between the weight and the amount of bend.

<u>Explore</u>: Is it linear? This leads to questions about what variation in the experiment that will change the outcome. Weight, placement of weight, material, and size of pipe are the variables one considers in this experiment.

<u>Explain</u>: Looking at those variations, the teacher will lead the class into a discussion of creating a function with an emphasis on which variables are directly or inversely affecting the bend.

<u>Elaborate</u>: The teacher will help the students find a function to fit the data, after they have attempted the experiment themselves. They will use calculators and Excel spreadsheets to find a best fit model.

<u>Evaluate</u>: Students will receive a worksheet that will help them collect, graph the, and answer questions about the data. A copy of their Excel spreadsheets that they use to find a model will be turned in.

Day 2:

<u>Engage</u>: The teacher will describe the self-sensing carbon nanotube threads in composite materials and how they affect any possible defects in the material. At this point, the teacher will show the video on nanotubes.

Explore: After handing out an equation sheet, the teacher will reflect on some of the equations that he/she used in the RET project. The teacher will explain the project, showing the data and graphs that they obtained. Handouts will be provided.

Explain: The teacher will re-teach how to solve for certain variables in the given equations.

Elaborate: The experiment part of the lesson comes next. The teacher will show students how they will be making their own self-sensing threads in a composite material. Taking tongue depressors, the teacher will show them how to glue the TDs together with a wire between them. They will cure overnight.

Evaluate: Students will develop skills for solving scientific equations for a given variable. They will start a lab report for the experiment they will do next day.

Day 3:

Engage: The teacher will fail a prefabricated bridge structure to show how the load-deformation relationship as load is increased up to failure. The bridge will be designed so that one of its members fails during testing. The cause of failure will be elaborated.

Explore: The teacher will use the bridge to analyze what went wrong? And could a sensor have helped detect when it was going to happen? Then, the teacher will show what the students will be doing with their experiments.

Explain: The teacher will show samples from RET project and some data that was found in the project. The teacher will show how the carbon nanotube threads play a part in the self-sensing of the composite material. This will lead to them doing their experiment.

Elaborate: After the experiment, the teacher will show to the students how to transfer the data, and, in a discussion of that ever important question: What did they find?

Evaluate: The students will finish lab report and make a poster with findings. They will present, as a group, the findings to the class.

Science Lesson Anatomy: A seven-day lesson plan was developed, presented below:

Teacher - Days 1-2:

- Warm-up: What holds us up? Describe how our support system works. (5 min)
- Open section with Bulldog Feud, to assess prior knowledge.
- Intro to the human skeleton PowerPoint presentation with coordinating worksheet.

Student - Day 1-2:

- Complete warm-up.
- Compete for a prize with teams.
- Fill in worksheet while going over chapter data.

Teacher - Day 3:

- Warm-up: What chemicals are an important part of a bone. (5 min)
- Begin lab.
- Assign research question:

- Research Osteoporosis: Describe the process that occurs in the development of osteoporosis.
- Compare the structure of normal bone to the structure of osteoporotic bone. Describe how normal bone functions.
- Predict how osteoporotic changes will affect the function of bone under stress.

Student - Day 3:

- Record initial data (mass, volume, and calculate density) of bone.
- Put bone in vinegar.
- Use microscope to view slides of bone, draw diagram of what is seen at 4x and 10x.

Teacher - Day 4:

- Warm-up: What are stress and strain?
- Introduce the concept of stress and strain and demonstrate how it is tested.

Student - Day 4:

- Remove samples from vinegar and rinse with water. Place in hood to dry.
- Design of a method to test how much stress the bone can take, sketch design in lab notebook, begin to build.

Teacher - Days 5-6:

- Warm-up: What do you think will happen to the decalcified bone under stress. How will that compare to normal bone.
- Remind students of research presentations.

Student - Days 5-6:

- Record dry data, draw a diagram of test, test stress/strain.
- Enter data into Excel and graph results.
- Complete conclusion.

Assessment - Day 7:

- Students will present, co teach exercise and be graded on rubric for comprehension.
- Students will be given a series of free body diagrams of different types of bones and be asked to label the forces that act on the bone.
- Predict the location of fractures when different types of bones are put under stress. Describe the difference in the location of fractures and the force necessary in diseased bone.