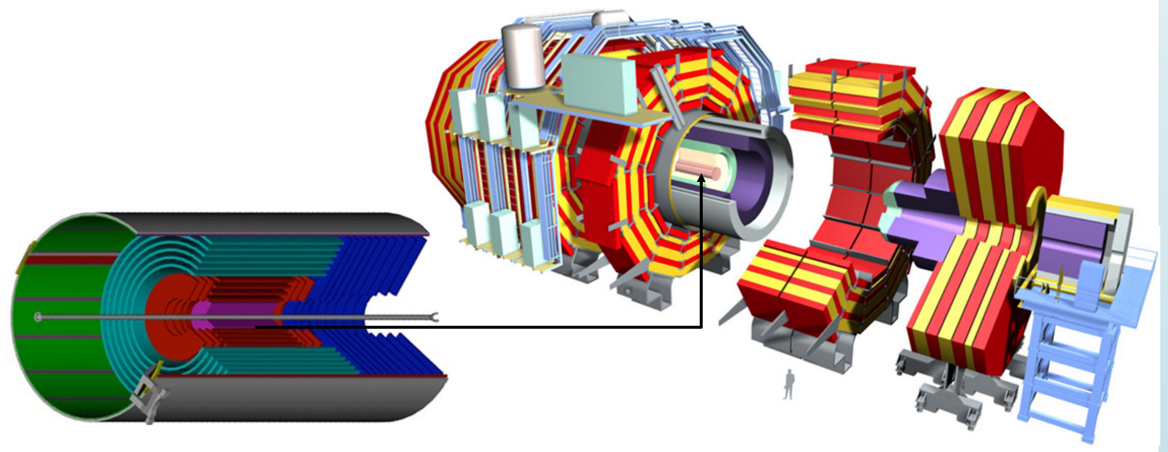
Strain Gauge Measurements of Carbon Fiber Dee for the CMS Phase-2 Upgrade of the Tracker Forward Pixel Detector

Diyaselis M. Delgado López[1], Dr. Jim Alexander[2], M. Eng. Yadira Padilla[2]

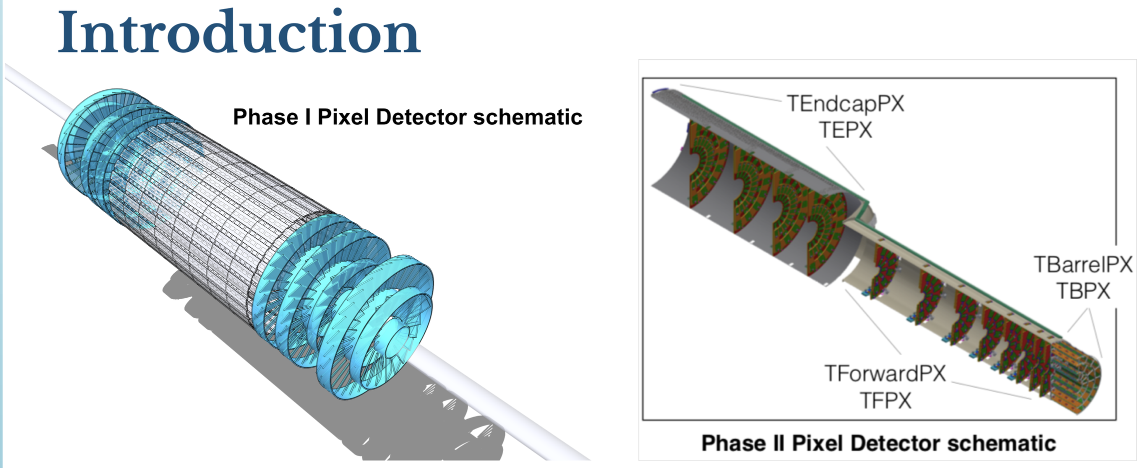
[1]University of Puerto Rico, Mayagüez, PR; [2]Cornell University, Ithaca, NY

Abstract

The silicon sensors of the TFPX are mounted on a carbon fiber structure called "Dee", due to its shape; it experiences deflection, upon thermal expansion and contraction of the material, and that deflection is measured by a strain gauge using a Dee prototype upon an applied load. The project entails the selection of a design for a strain gauge experiment to measure deflection and failure in carbon fiber used in the Dee. Based on the acquired data, a material profile for carbon fiber is used as a guideline for the Dee's construction and modeling as part of the Phase-2 Upgrade of the Forward Pixel Detector from the CMS Experiment.

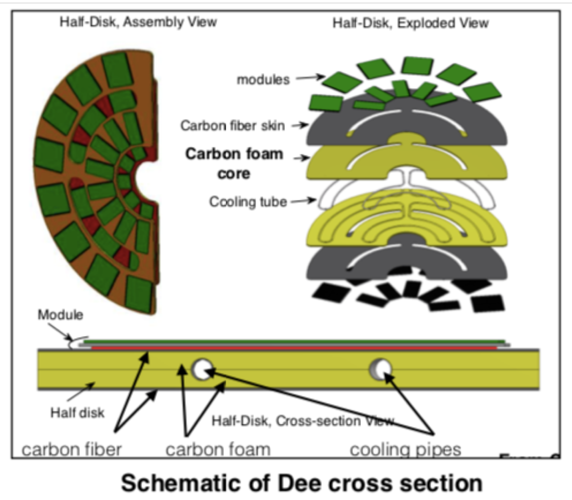


Introduction



During the testing of the materials, some of the properties of interest are the Young's modulus and the Poisson's ratio. Young's modulus refers to the numerical value of the elastic property of a material, which represents the ability to deform the material. The Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of a stretching force[1]. These properties will help determine the strain, the amount of deformation of a body due to an applied force, of each of our testing samples. The project focuses on testing the strain properties of a carbon-carbon composite, the leading material for the construction of the Dee's of the CMS Tracker Forward Pixel Detector.

Carbon fiber is a unique material due to its intricate layers and direction of carbon fiber tubes upon construction, which makes the effect of stress and strain on carbon fiber materials change with the direction which it is applied.

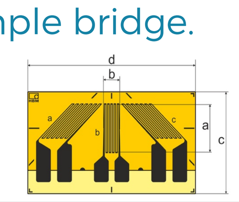


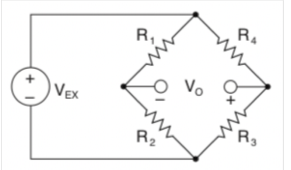
Schematic of Dee cross section

The carbon fibers themselves are much more brittle than metal, but the matrix of the carbon fibers allows for one individual carbon fiber to fail without the failure of the entire piece due to surrounding fibers compensating for the failure. Carbon foam is then glued and cured as an intermediary layer of the carbon fiber Dee, which changes the Poisson ratio of the total material, but in fact resulting in a more sturdy composition overall.

Materials

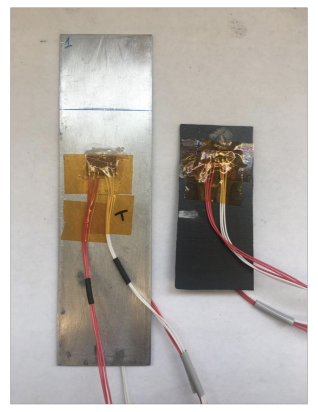
While there are several methods of measuring strain, the most common is with a strain gauge, a tool whose electrical resistance varies in proportion to the amount of strain in the device[2]. The Wheatstone bridge is the most used circuit to measure strain of an applied strain gauge by measuring the voltage difference between two ends of a simple bridge.





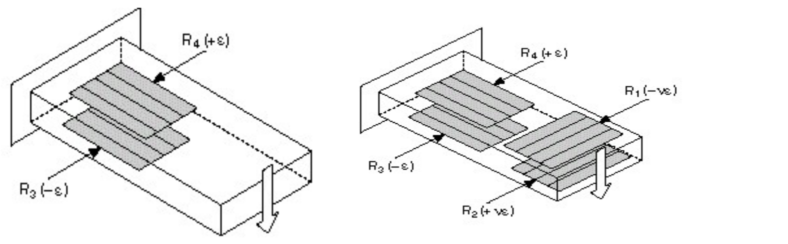
The samples that underwent testing were a carbon fiber-foam, a carbon fiber-foam-fiber and an aluminum control piece. By using both a half and full Wheatstone bridge configurations of strain gauges, 4 and 2 gauges attached, respectively, both the Young's modulus and Poisson's ratio of the materials can be calculated.

The strain gauges were glued to the materials with epoxy, to ensure the connection between the two. The contribution of the epoxy to the strain measurements were ignored for initial tests.

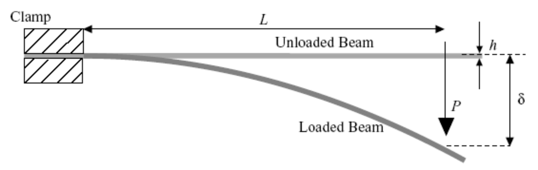


Methodology

When testing our materials, the type of measurement taken were to study bending strain. Bending strain is caused when strain is applied to an axis perpendicular to the material, therefore causing one of the faces of the material to undergo compression and the other, expansion.

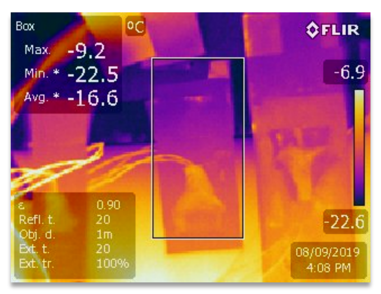


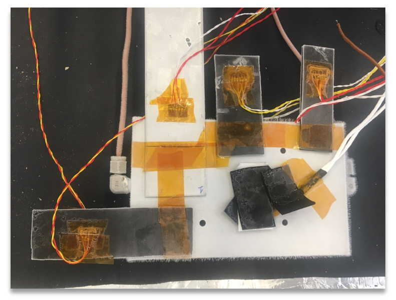
A proposition for testing the strain of the carbon fiber was the Cantilever beam bending test. A load is placed at the end of the beam, creating a bend in the material that is then measured by the change of resistance in the attached strain gauges.

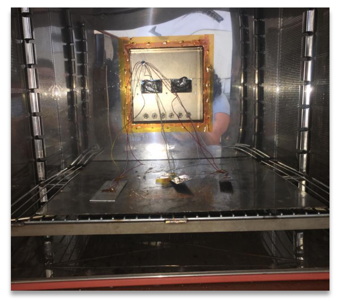


The thermal expansion coefficient is another physical property considerably important in the mechanical and structural design applications of the carbon fiber. When a strain gauge is installed on a stress-free sample and the temperature of the material is changed, the output voltage from the gauge changes as well, hinting that the material is being strained.

The thermal shock test implemented involved placing the material in an oven and heating it up, as the changes in resistance where measured from a DAQ system. Tests with CO[2] cooling were also executed on the material samples.





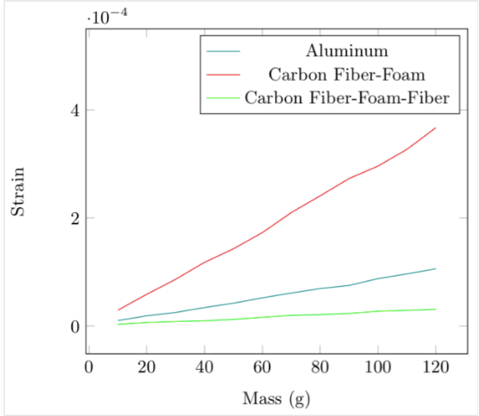


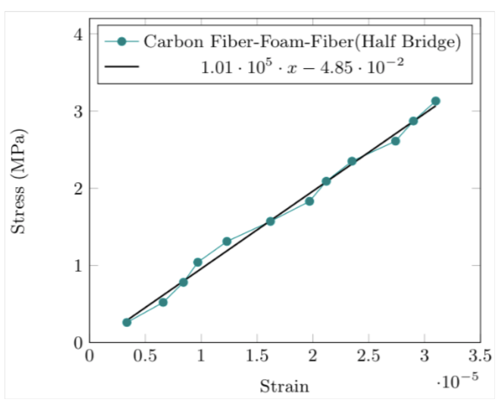
Results

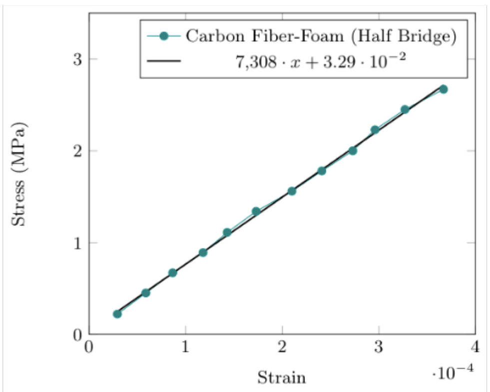
Results of the Cantilever experiment were initially collected from the DAQ system stationed at the CMS Lab. The data logger was programmed to process the output voltage across the circuit and calculate the voltage ratio, strain, stress, Poisson's ratio and finally, Young's modulus.

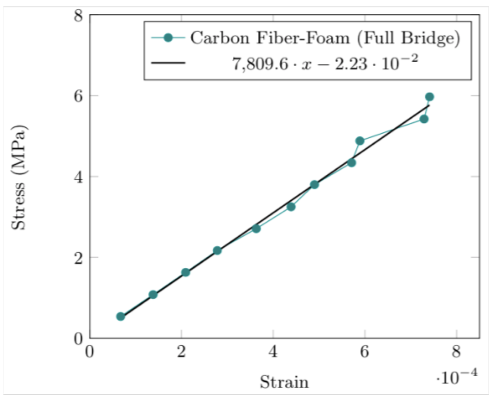
$$\epsilon_{HalfBridge} = \frac{-2V_r}{GF} \cdot \left(1 + \frac{R_L}{R_G}\right) \qquad \epsilon_{FullBridge} = \frac{-2V_r}{GF(\nu+1)}.$$

Using the 3-grid gauges of 120 Ω resistance in a half and full Wheatstone bridge configuration, wires with lead resistance of 12 Ω, and an initial source voltage of 0.5 V, approximately, test results for this sample are shown below.





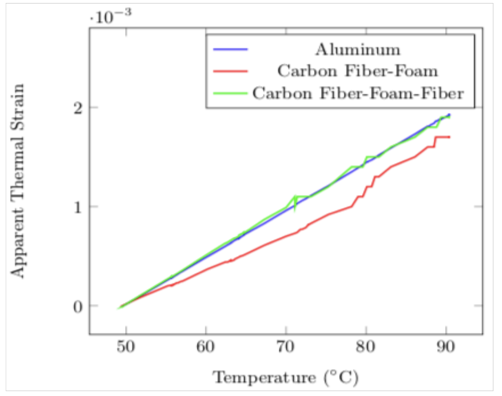


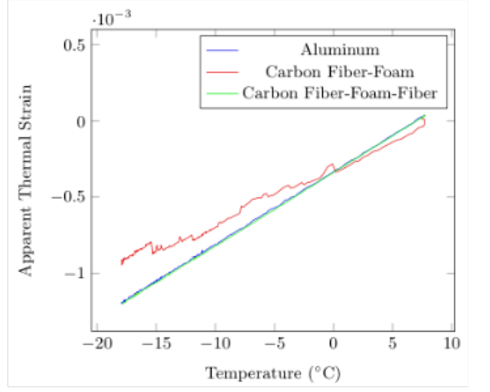


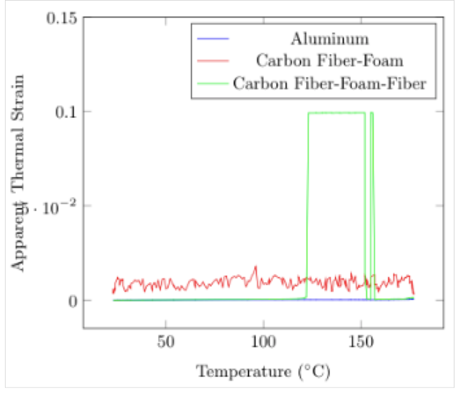
Additional results from the thermal shock experiment were taken from the data logger and individually analyzed.

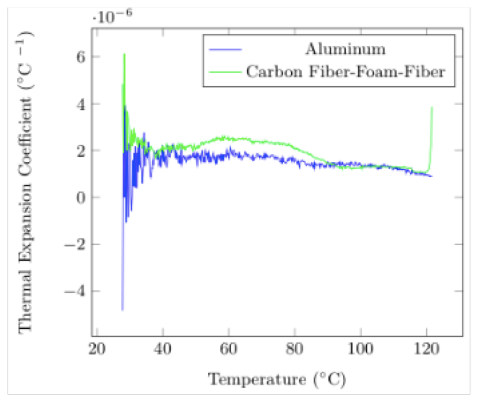
$$\epsilon = \frac{\alpha}{GF} + (\beta_S + \beta_g)$$

The material samples underwent temperature changes from the range of -20 °C - 180 °C, depending on the test runs.









Another factor to consider is the time period it took for these measurements to stabilize. Also once strained and relieved, the time period of recovery of the material (i.e. to obtain a similar result to the unstrained case.) was measured to observe the behavior of the samples..

Conclusion

The overall experiment was developed to measure the mechanical deformation and the thermal expansion of carbon-carbon composites.

The main parameters of testing is an input force range of 0.1 to 1.2 N and temperature range from -25 °C to 180 °C.

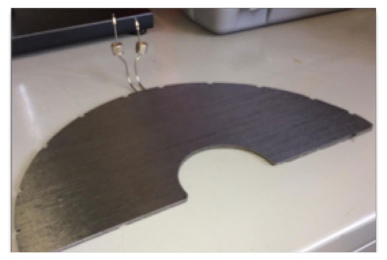
Strain gauge measurements were made on aluminum, carbon fiber-foam and carbon fiber-foam-fiber samples with the means of measuring the Young's modulus, the Poisson's ratio and the thermal expansion coefficient of each one, along side with their strain and stress, mechanical or thermal.

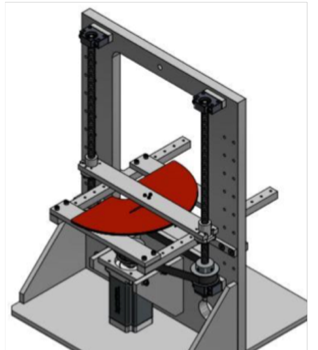
The carbon fiber-foam-fiber piece proved to be the stiffest amongst the samples tested. For the carbon fiber-foam, the Young's modulus is 7.53 ± 0.22 GPa, the Poisson's ratio is 0.32 ± 0.13. For the carbon fiber-foam-fiber, the Young's modulus is 96.5 ± 4.50 GPa.

These were preliminary results of mechanical and thermal properties. Further testing is needed for the full Dee structure.

Recommendations

Mechanical stress on a full Dee should be exerted in a tensile stress machine for an optimal experiment. For thermal experimentation, the expansion rate for the carbon-carbon composites is extremely sensitive, and delamination is the biggest factor to account for. Further test should include the placement of gauges inside the carbon fiber-foam 'sandwich', to observe behavior due to cooling tube's interaction..





References

[1] N. Mahalik, in Mems (Tata McGraw-Hill Education, 2008) Chap. 3, pp. 102–104.

[2] National Instruments, *Measuring Strain with Strain Gages*.

Acknowledgements

This project was funded by National Science Foundation's High-Luminosity LHC U.S. CMS Detector Upgrade Project.

Special thanks to the Society of Physics Students, the American Institute of Physics and the American Physical Society for the MSI Award which supported this poster.

Many thanks to my advisor **Dr. Sudhir Malik** for supporting me while I further my research experience; as well as my supervisor Dr. Jose Monroy.