Design and Fabrication of a Joule Heated Fiber-Reinforced Carbon Aerogel for Insulation

Stephen Barbagallo, Ellen Cesewski, Naveed Chowdhury, Joseph Langreo, Colin Qualters, Nathaniel Schreiber
Department of Materials Science and Engineering, University of Maryland, College Park, MD 20742

Background

Cold Weather Clothing
Current high-performance clothing systems that are designed to assist the wearer in combatting extremely cold weather situations rely heavily on the concept of layering in order to protect and insulate. A Joule-heated, ultra-lightweight material could be a solution to actively warm the wearer in addition to providing thermal insulation. A battery-powered product like this could greatly benefit the cold weather clothing industry.

Joule Heating
Charge carrier collisions transfer kinetic and vibration energy to ions, which often manifests as heat within the industry. Therefore, thermal insulation. A battery-powered product like this heated, ultra-lightweight material could be a solution to layering in order to protect and insulate. A Joule-designed to assist the wearer in combatting extremely cold weather conditions.

Current high-performance clothing systems that are designed to assist the wearer in combatting extremely cold weather situations rely heavily on the concept of layering in order to protect and insulate. A Joule-heated, ultra-lightweight material could be a solution to actively warm the wearer in addition to providing thermal insulation. A battery-powered product like this could greatly benefit the cold weather clothing industry.

Joule Heating
Charge carrier collisions transfer kinetic and vibration energy to ions, which often manifests as heat within the industry. So-called Joule heating can be used to our advantage to actively heat a material using current.

Carbon Aerogels and Carbon Fibers
Carbon aerogel is an ultra-low density, highly porous material made up of a fibrous carbon network. Carbon fibers are highly conductive fibers and are also quite flexible, lending increased electrical conductivity and flexibility to a carbon aerogel. Carbon fiber-reinforced carbon aerogels (CFCA) have been investigated for their thermal and electrical properties, but have not previously been designed for a Joule heating application.

Carbon Aerogel
Carbon aerogel is an ultra-low density, highly porous material made up of a fibrous carbon network. Carbon fibers are highly conductive fibers and are also quite flexible, lending increased electrical conductivity and flexibility to a carbon aerogel. Carbon fiber-reinforced carbon aerogels (CFCA) have been investigated for their thermal and electrical properties, but have not previously been designed for a Joule heating application.

Research Questions
(i) Will carbon fiber-reinforced carbon aerogel thermally perform as well as synthetic down with marginal heat generation from Joule heating?
(ii) Which variation in processing parameters will yield an aerogel with minimum thermal conductivity for a practical electrical property for joule heating potential?

Design and Modeling

CFCA: Carbon fiber-reinforced carbon aerogel
Design Components
Volume fraction of carbon fibers
Porosity: pore size, pore density
Monolith shape and thickness

Desired Performance
1. Acts as a thermal insulator
2. Joule heating capability
3. Flexible, mechanical durability

Line scan:
\[ R_{\text{fin}} = (\text{blue}) + (R_f + \text{red}) + (R_{\text{ins}}) + (\text{blue} - \text{red}) + (R_{\text{fin}}) \]

Sheet Resistance:
\[ R_{\text{fin}} = \frac{1}{N} \]

As we increase fiber fraction content, the distribution of sheet resistivities increases due to increased fiber connectivity in the composite.

Power Generation

Promising power generation for current applied across thin strips of composite instead of bulk fabric form.

Future Directions
- A controllably Joule-heated aerogel should continue to be studied for both wearable and non-wearable applications.
- Our next steps would be to fabricate samples using a supercritical dryer and to thoroughly characterize electrical and thermal performance as part of a device or component.

Acknowledgements
Dr. Ray Planek
Dr. Robert Bonenberger
Dr. Yifei Mo
Dr. Liangbing Hu
Doug Henderson

References