

# INDUSTRIAL APPLICATIONS OF CARBON AND GRAPHITE FOR THERMAL MANAGEMENT

*At GrafTech International, carbon and graphite products are designed and manufactured for use in everything from industrial induction furnaces to consumer electronics. Numerical analysis is the key to design and process optimization for any application, making it possible to maximize performance while keeping power consumption and material expenditures in check.*

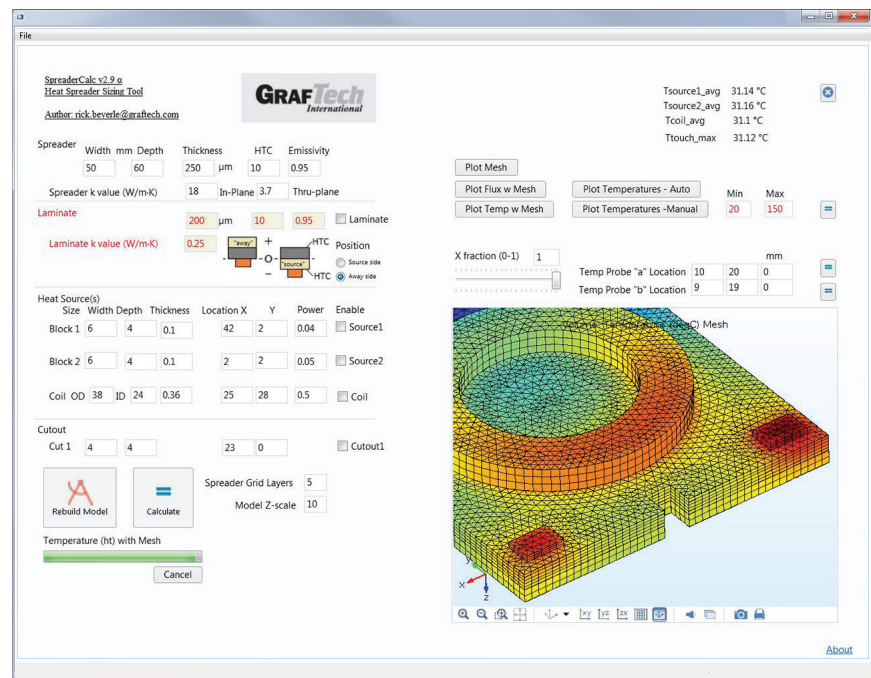
By **JENNIFER SEGUI**

**IDENTIFYING AND DESIGNING** the best materials for a particular thermal management application can be a challenging task, where industrial designers are presented with countless options from suppliers, and often not enough information to make an informed decision.

Researchers and engineers at GrafTech International place significant value on understanding their products, allowing them to provide their customers with the information they need to select the right carbon and graphite solutions.

“To better understand our products and how they perform in the context of a particular thermal management application, we are using numerical simulation in combination with physical testing,” explains Richard Beyerle, a senior scientist in the Innovation and Technology group at GrafTech. “The latest computational tools that we have under development may also be used by our sales engineers, field specialists, and customers to compare how our products perform in virtual prototypes before proceeding to physical implementation and testing.”

An example of one such tool, a computational application, is shown in Figure 1. The application provides a user-friendly interface to an underlying mathematical model, making it straightforward for anyone who would benefit to run simulations.



**Figure 1.** A simulation application combines a user-friendly interface with an underlying multiphysics model, extending analysis capabilities to a broad pool of users. This app allows its user to compare heat transfer among graphite foils, which are used to dissipate heat in consumer electronics. Image courtesy of GrafTech International.

The use of numerical simulation, and more specifically multiphysics modeling, is prevalent throughout the Innovation and Technology group. “Actually, all of our products and applications have seen the use of multiphysics simulation,” says Ryan Paul, Innovation & Technology Manager at GrafTech.

In their work, Beyerle, Paul, and senior scientist Nathanael May use multiphysics modeling and simulation applications to better understand the electrical, structural, and thermal performance of carbon and graphite, as well as for design and process optimization for several industrial applications.

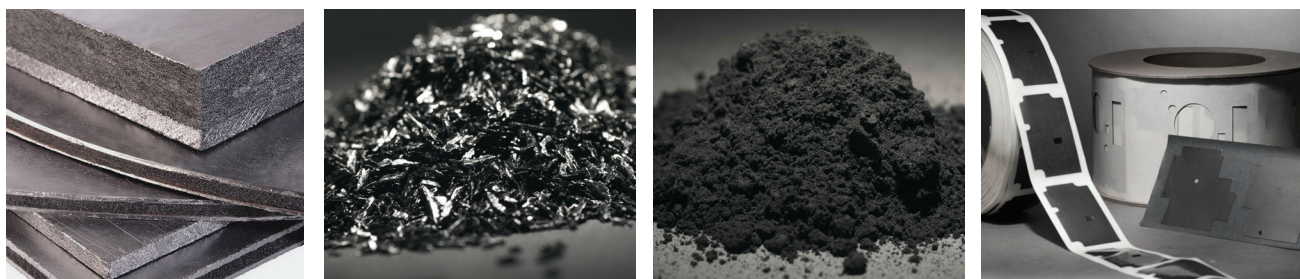


Figure 2. The advanced material solutions designed and manufactured by GrafTech include rigid composite sheets, expanded flakes, powders, and flexible graphite foils, among many other custom options. Photo courtesy of GrafTech International.

“The [simulation apps] that we have under development may also be used by our sales engineers, field specialists, and customers to compare how our products perform in virtual prototypes.

— RICHARD BEYERLE,  
SENIOR SCIENTIST,  
GRAFTECH INTERNATIONAL

## » UNDERSTANDING CARBON AND GRAPHITE

THE ADVANCED MATERIAL solutions manufactured by GrafTech from carbon and graphite are available in many physical forms including rigid sheets, felts, powders, flexible foils, and custom-machined structural elements, a selection of which are shown in Figure 2. Both amorphous carbon and graphite are depicted in Figure 3 for comparison, and are made up of the chemical element, carbon. Relative to amorphous carbon, graphite has a highly ordered structure consisting of many planar layers. Within a single layer of graphite, a honeycomb lattice is observed, where covalent bonds between carbon atoms produce a hexagonal arrangement.

The structure of graphite results in excellent in-plane electrical and thermal conductivity, particularly in comparison to amorphous carbon. Graphite is also extremely strong, with a single layer of graphite, referred to as graphene, being the strongest

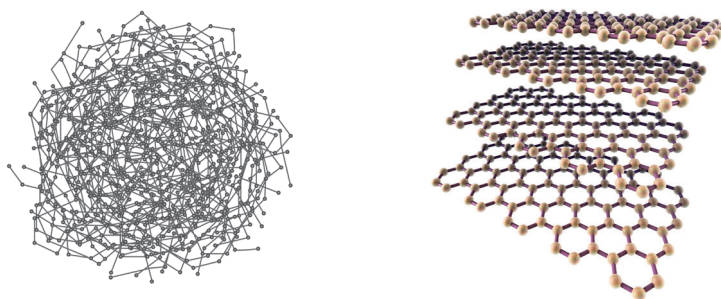


Figure 3. Compared with amorphous carbon (left), graphite has a highly ordered structure consisting of individual layers of graphene (right).

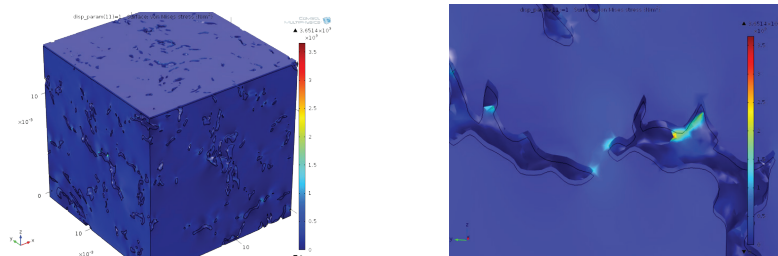


Figure 4. A reconstructed volume of graphite showing material porosity was generated using computed tomography (CT) and imported into COMSOL® software for simulation. The validated model is being used to investigate the effect of porosity on the elastic properties of synthetic graphite. Images courtesy of GrafTech International.

material on record. However, weak bonding via van der Waals forces between the layers in graphite results in lower through-plane electrical and thermal conductivity, which gives graphite its highly anisotropic properties. Individual layers are also able to slide past each other making the bulk material relatively soft. Many forms of graphite, however, can withstand temperatures in excess of 3000 degrees Celsius in

a non-oxidizing atmosphere.

In order to use graphite in applications where thermal management is important, and benefit from its unique thermal properties, it is necessary to better understand how the material performs overall. A combination of physical characterization and simulation in COMSOL Multiphysics® software is being used at GrafTech for this purpose, as shown in Figure 4.

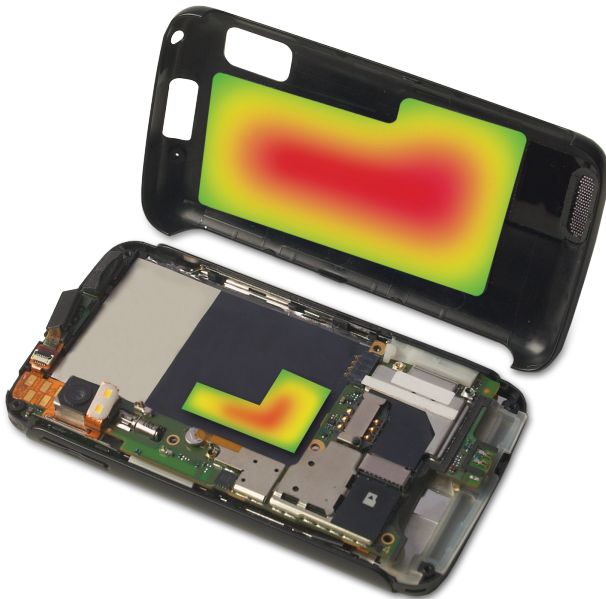


Figure 5. Flexible graphite foil heat spreaders enable dissipation of heat from an electronic component with high in-plane conductivity, while protecting underlying heat-sensitive areas with low through-plane conductivity. Photo courtesy of GrafTech International.

heat spreaders, for example, are among the graphite foils available, and are designed for use in different applications such as smartphones, tablets, and displays. Figure 5 illustrates how graphite heat spreaders work to cool an electronic component or device, which allows them to operate at lower temperatures, extending their lifetimes and improving their performance.

Graphite foil heat spreaders come in a select range of thicknesses, electrical and thermal conductivities, contact impedances, and coating options. “It is a common challenge to balance the desired thermal performance and cost,” says Beyerle. “Numerical simulation is an excellent way to evaluate how a graphite foil will perform for cooling electronic components in a particular device, enabling us to identify the most cost-effective solution for our customers without compromising performance.”

To evaluate anisotropic heat transfer, and the performance of flexible graphite foils for thermal management in various electronics applications, Beyerle is developing mathematical models and simulation applications in COMSOL Multiphysics® software. One custom application enables the user to evaluate graphite heat spreaders in geometries that are relevant to portable electronic devices, such as cell phones, and was introduced in Figure 1.

The application provides the ability to change the location and size of heat sources, slots, and other openings, specify the heat source power, and visualize the finite element mesh and simulation results. Figure 6 shows how changing the slot length, for example, can affect heat

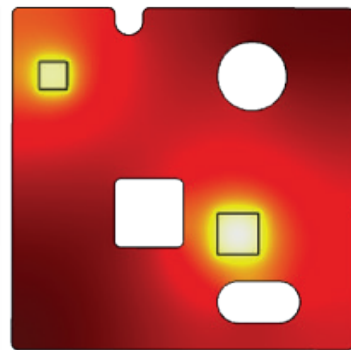
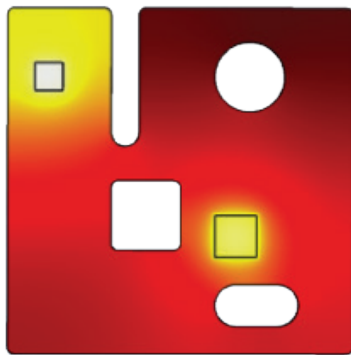


Figure 6. By using GrafTech’s simulation application, heat dissipation throughout a graphite heat spreader can be evaluated, taking into account the size and placement of heat sources as well as the size of cutouts. Images courtesy of GrafTech International.

“The design challenge is to model the temperature-dependent properties and performance of graphite under dynamic thermal-mechanical-electrical loads,” explains Paul. “By modeling graphite and its applications, learning happens much faster, and builds on experiment by deepening our understanding of the mechanisms and theory, something experimental data alone cannot deliver.”

### » MODELING GRAPHITE FOIL FOR ELECTRONICS COOLING

**FOR ONE POTENTIAL APPLICATION** — the thermal management of electronic components — GrafTech designs and manufactures thin flexible graphite foil. SPREADERSHIELD™

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— RYAN PAUL, INNOVATION AND TECHNOLOGY MANAGER, GRAFTECH INTERNATIONAL



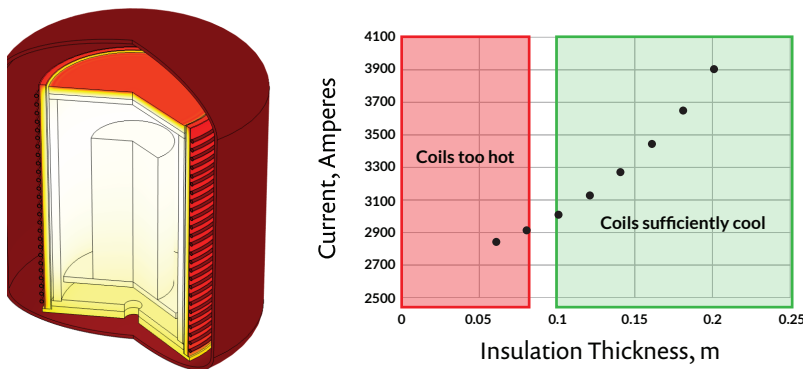


Figure 7. At left, temperature distribution from simulation of a furnace with water-cooled induction coils. Right, results demonstrate the optimal graphite insulation layer thickness required to cool the coils. Images courtesy of GrafTech International.

dissipation from a nearby source.

To ensure the simulation app is a useful tool, an important step is verifying the underlying mathematical model. A particular concern for Beyerle is the accurate simulation of anisotropic heat transfer in both flat and curved layers of graphite heat spreaders. In this case, if the simulation is not accurate, the results could make the unique performance of graphite appear similar to that of an ordinary metal. In COMSOL® software, it is straightforward to create a user-defined coordinate system for modeling anisotropic material properties, including in curved or branched parts.

Running a simulation through the app was designed to be quick, taking less than 12 seconds, making the tool convenient for use during the sales cycle. By using an installation of the COMSOL Server™ product, Beyerle is able to host the simulation app on local hardware at GrafTech, while giving colleagues and customers the ability to run the app remotely from a COMSOL Client for Windows® operating system or from a web browser.

### » OPTIMIZING FURNACE DESIGN AND OPERATION

DESPITE THE NUMEROUS ADVANTAGES of using graphite in practice, the anisotropic and highly temperature-dependent properties of the

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many unique grades of materials manufactured by GrafTech can be challenging to model accurately – a challenge clearly shared by Beyerle and Paul, as well as by their colleague Nathanael May, a senior scientist also in the Innovation and Technology Group.

“Having many unique grades of materials means we have to do the lab work to build a database of material properties that we can use in our models,” explains May. “The effort is easily justified, though. Virtual prototyping through mathematical modeling is very useful for increasing the confidence of potential customers, allowing us to demonstrate that GrafTech’s solutions are thoroughly vetted.”

One of May’s major projects is dedicated to creating a sophisticated multiphysics model using COMSOL Multiphysics. “I am mostly creating models for simulating

high-temperature furnaces, in 2D and 3D, such as induction furnaces, vacuum furnaces, and high-quality crystal growth furnaces,” says May.

An example of an induction furnace from May’s work, as well as results from design optimization performed using numerical simulation, is shown in Figure 7. Simulation was used to optimize the thickness of a GRAFSHIELD™ carbon bonded graphite insulation layer in order to prevent temperatures from exceeding 100 degrees Celsius in the water-cooled induction coils. Additionally, keeping the insulation layer as thin as possible reduces the amount of current required to maintain the furnace temperature.

### » THE WIDE WORLD OF CARBON AND GRAPHITE

WHEN IT COMES TO GAINING a better understanding of the performance of GrafTech’s unique carbon and graphite solutions, modeling and simulation are essential. Equally adept at both experimental characterization and computational modeling, Beyerle, Paul, and May are combining the two, making application-specific information about GrafTech’s solutions available.

By developing and deploying custom applications — an exclusive capability in COMSOL Multiphysics® software — GrafTech can provide easy-to-use, simulation-based design capabilities for thermal management applications. In this way, simulation applications not only open up the wide world of carbon and graphite, but numerical analysis as well, to any colleagues or potential customers who would benefit. ☺



Richard Beyerle is a senior scientist in the Innovation and Technology Group at GrafTech International.