New Simulation Software Tool Successfully Used in Carburizing Gears

By Sherri Mabry

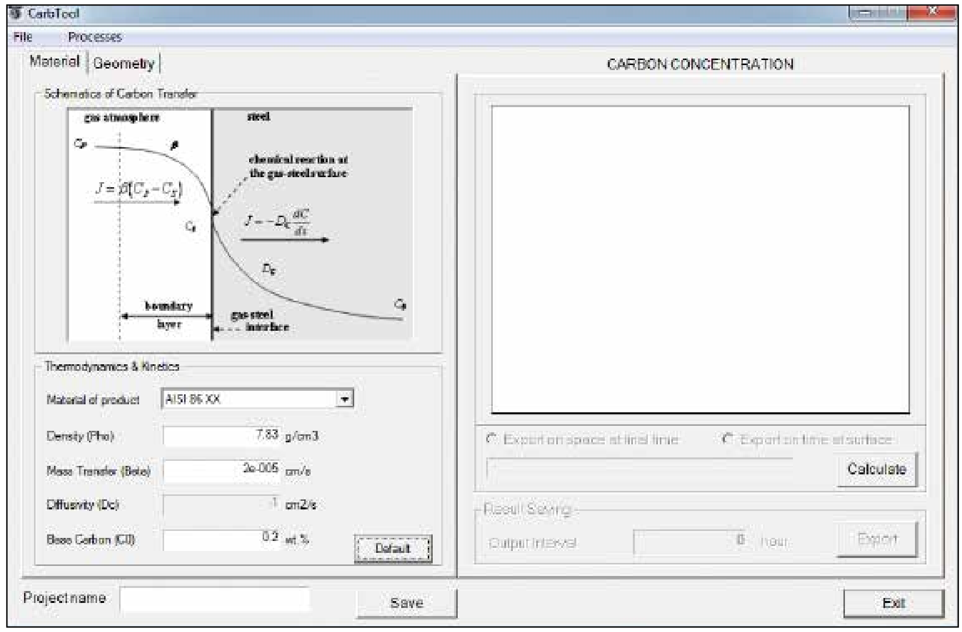
CarbTool is designed to assist heat treaters in understanding and modeling the effects of process parameters on case depth, carbon concentration, microstructure, stress and distortion.

In 1999 when the Center for Heat Treat Excellence (CHTE) was formed, the idea was to develop collaborative research between the industrial sector and university leaders to address the short and long-term needs of the heat-treating industry.

One significant creation of that collaboration was the development of software to simulate the carburization heat treat of steels known as CarbTool. This software predicts the carbon profile and case depth of carburized steels by modeling the absorption and diffusion of carbon during the carburization processes.

CarbTool software has been successfully used to develop the process parameters for carburizing aerospace and automotive gears. The results of the simulation can be used as the initial conditions for finite element model (DANTE and DEFORM) to predict the distortion, residual stresses and microstructure of carburized 8620 and 9310.

Dr. Richard D. Sisson, Jr., George F. Fuller Professor, dean of graduate studies and director of manufacturing and materials engineering at the Worchester



Polytechnic Institute in Worcester, Massachusetts, said a simulation tool was developed at the CHTE by students at WPI for the calculation of carbon concentration profiles during the gas and vacuum carburizing process.

"We have a fairly large research institute, the Metal of Processing Institute, led by professor Diran Apelian, that includes three research centers, including one for heat treating," Sisson said. "The center is made up of 30 member companies that each contribute up to $25,000 annually to support our research projects. These companies include major corporations, such as John Deere, Caterpillar, Chrysler and others. They get access to our students in materials engineering in research for metal casting, recycling, and heat treating."

Dr. Sisson said, "Steel is an alloy composed of iron, carbon, and other elements. The more carbon in the mixture, the more that heat-treating is required to obtain the desired properties. By heating the steel in a carbon rich atmosphere, the carbon is absorbed and diffuses into the steel at high temperatures of 1500 to 1700 degrees, so the gas carburizing process is to heat to high temperature in an atmosphere that is rich in carbon and bring the surface carbon from two percent to up to 0.90 weight percent. After the carburizing heat treatment, the steel must be quenched in oil or high-pressure gas to form Martensite. This makes the steel very hard, but brittle, so you need to temper the steel to restore the toughness. In vacuum carburizing, steel goes through many carburizing cycles where the metal is heated in a vacuum with a small addition of a hydrocarbon gas to allow the steel to absorb the carbon. The gases such as acetylene or methane are added into the vacuum furnace. As few as two to three cycles or up to hundreds of cycle may be used depending on the steel alloy and part geometry as well as the hardness required.

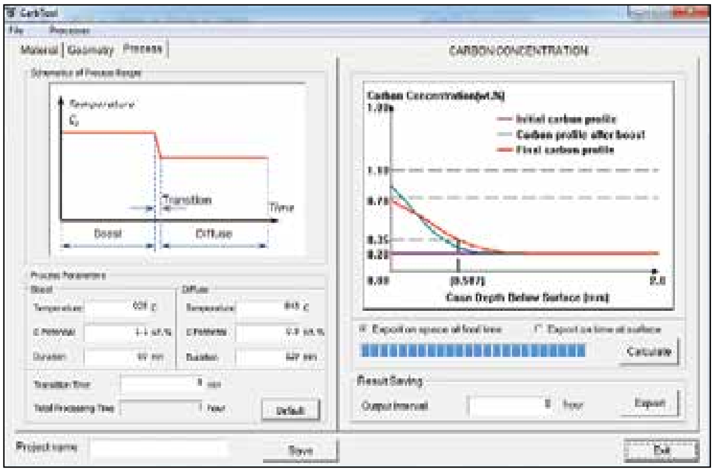
In order to develop and optimize the carburizing process, heat treaters often use trial and error to determine process parameters, according to Sisson, who says these methods are time consuming and expensive with sometimes poor results. The challenge for CHTE and the students and professors at WPI was to develop models that could be used to determine the most effective treatment process parameters for a particular application.

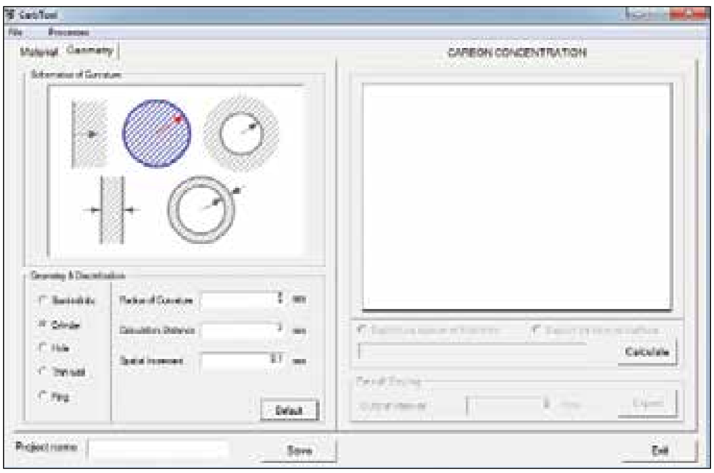
CarbTool was developed to calculate the carbon concentration profile in the steel during the gas and vacuum carburizing process by creating an algorithm based on the finite method (FDM), and C++ programming in Microsoft Visual Studio.

"The tool we developed is based on the concept of the carbon flux at the surface between the gas and steel," he said. "CarbTool outputs the carbon concentration and the distribution profile inside the steel or the surface carbon concentration profile is defined as a function of time."

"In vacuum heat treating we are controlling the temperature, the time and fluxes in a gas chamber where the potential for carbon escaping into the atmosphere is possible," he said. "CarbTool simplifies this process to flux versus time so we pump out the gas, introduce another gas, pump out the gas, and plot the results as gas pressure to export data for the calculation results. It uses finite difference method to calculate the parameters. We are working on the future of heat-treating where we study the hardness as a function of depth. Empirically, this steel carbon profile is quenched and this gives the hardness graph of the right iron carbon phase."

Sisson said the software has an ID mass diffusion model that simulates the semi-infinite and cylindrical geometry of a structure, including thin walls, and it can also calculate inverse to optimize the parameters based on the surface carbon and case depth. Carbon concentration and microhardness in the layer can be predicted by using the software by entering known diffusional interactions that are included in the model.





Users input data, including the carburization temperature, time, and carbon potential or flux, and by using the simulation software, the heat treater can determine the carbon concentration below the surface to plot case depth according to a user-defined value.

Sisson said developing the carburizing software allows users to export data such as cyclic and non-cyclic pulse processes, carbon profiles at certain intervals and final times with an effective case depth indication at 0.35 wt. % C or at a user defined value. It also shows surface carbon saturation and indicates the carbon concentration for cementite formation, which can be controlled.

According to this process, the methodology of the vacuum carburizing process simulation shows: To determine the vacuum carburizing-carbon flux calculation, tentative samples are carburized and measured and the CarbTool verifies the results. This program also produces a revised recipe based on the flux calculated. By taking comparisons between CarbTool simulation and the experimental samples, the test can be verified.

Sisson said CarbTool has a 1D mass diffusion model, which is capable of simulating the gas and vacuum processes in both Cartesian and cylindrical coordinates.

Based on the research, vacuum or low-pressure carburizing followed by high-pressure gas quench is an effective process for heat-treating gears. For more information, email sisson@wpi.edu or visit www.wpi.edu.

FOR MORE INFORMATION: Richard D. Sisson, Jr. is dean of graduate studies, George F. Fuller Professor, and director of Manufacturing and Materials Engineering at Worcester Polytechnic Institute. You can contact him at sisson@wpi.edu

THE CENTER FOR HEAT TREAT EXCELLENCE AND THE METAL PROCESSING INSTITUTE AT WPI

The Center for Heat Treat Excellence (CHTE) collaborative with the Metal Processing Institute at Worcester Polytechnic Institute in Worcester, Massachusetts is an alliance between the industrial sector and university researches to address short-term and long-term needs of the heat-treating industry.

CHTE provides a critical forum where various segments of the industry pool their resources to develop research used to advance the heat-treating industry by developing a knowledge base and curricula for education purposes.

ACHTE along with ASM's Heat Treat Society have worked together to establish a database to serve the $20 billion-a-year industry comprised of materials scientists and engineers. The database is organized in 16 main categories, and the data is entered and managed by the researcher for the organization participating, where researchers can inform the world about the work they are doing.

By applying fundamental research to solve problems, this member-driven team enhances the industry's technology base, profitability, public images and the education of its members.

Industrial members include commercial heat treaters, captive heat treaters, heat treat industry suppliers, and manufacturers of products using heat-treating technologies. The center is governed by a board of directors with responsibilities to facilitate, guide, and review research programs.

WPI faculty at the center includes Diran Apelian, Makhlouf Makhlouf, Richard Sisson, and Kevin Rong. CHTE also has alliances with faculty at other universities where research is carried out.

The Metal Processing Institute (MPI) at Worcester Polytechnic Institute (WPI) has access to a full complement of material engineering and processing facilities, including x-ray fluorescence, metal and casting laboratories, imaging and sensing, and thermal processing.

The institute is supported by more than 90 corporate partners, as well as funding from private foundations and the federal government. During the last decade, MPI has developed into on of the nation's premier research centers dedicated to metal processing.

The MPI is staffed with qualified research scientists and post-doctoral fellows, and is fully equipped with melting furnaces, including electrical and induction furnaces, heat-treating furnaces, rotary degassers, an Alscan unit, a reduced pressure testing unit, a spectrograph, and optical and scanning electron microscopes equipped with energy dispersive x-ray analysis capabilities and image analysis capabilities. In addition, MPI has all the necessary mechanical testing equipment, including Universal testing machines with temperature chambers, fatigue-testing machines, and measuring equipment for impact, toughness, hardness and micro hardness.

There is a casting and heat-treating lab, a sample preparation lab, thermal analysis lab, microscopic analysis lab, mechanical testing lab, software simulation lab and a miscellaneous lab with x-ray diffraction and high temperature rheometers.

Since its creation, CHTE has established liaisons with the Metal Treating Institute (MTI) and the Heat Treating Society (HTS) of ASM International. CHTE researches participate in meetings of MTI and the R&D committee of HTS to ensure communication and active dialogue between the association and the professional society exists.

MPI has established alliances with several key universities and laboratories around the world in the past decade, where faculty and research staff shares annual visits, jointly manage projects, share adjunct faculty and collaborate on short courses and symposia. MPI is allied with Steel Research Group at Northwestern University, the Colorado School of Mines in Golden, Colorado, L'Ecole Nationale Superieure des Mines d Saint-Etienne, Saint-Etienne, France, Northwestern Polytechnical University, Norwegian University of Science and Technology, TWTH Aachen University in Germany, Foundry Institute, the Forging Institute, Tsinghua University, University of Padova and the University of Queensland. They have also formed alliances with several corporations and organizations, including CompuTherm LLC, ESI, Inc., Light Metals Alliance, MAGMA, Material Connexion and Thermo-Calc Software.

The center works to develop processes to control microstructure and properties of components, reduce energy consumption, reduce process time, reduce production costs, achieve zero distortion, increase furnace efficiency and achieve zero emissions.

Each year the CHTE acknowledges the accomplishments of an individual who has made significant, commendable and long-standing contributions to the promotion of CHTE. Criteria include an active CHTE membership in good standing for a minimum of three years and exceptional contributions to CHTE.

Previous award recipients are Max Hoetzl (2012), Robert Gater (2011), Roger Fabian (2010), and William J. Bernard (2009).

For more information, visit www.mpi@wpi.edu or call 508-831-5993.