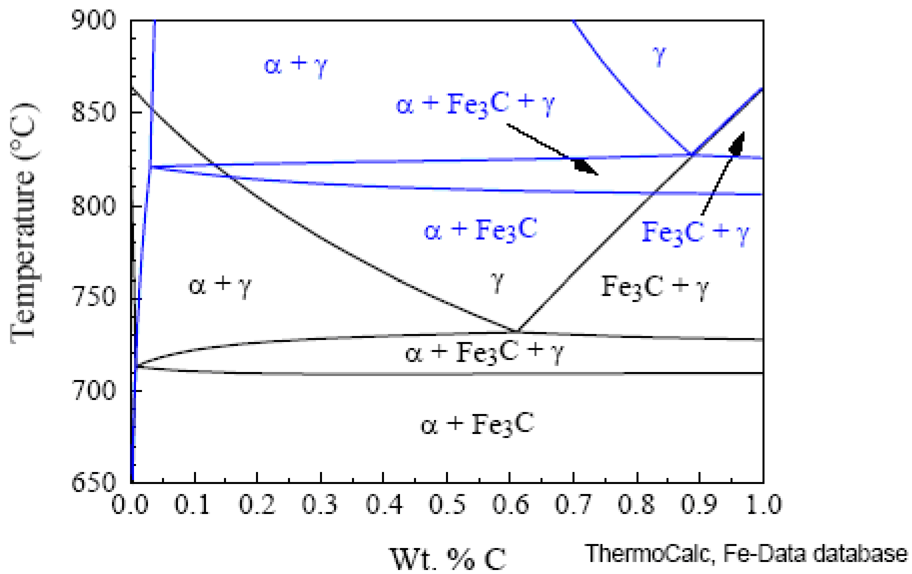
Industrial Technologies Program

Exploring Ultrahigh Magnetic Field Processing of Materials for Developing Customized Microstructures and Enhanced Performance

A New High-Payoff Industrial Processing Methodology Whereby Alloys and Microstructures with Superior Properties will be Developed

Essentially all materials have some form of ferromagnetism or paramagnetism. This property makes magnetic field processing directly applicable to a multitude of materials for dramatically influencing phase stability and phase transformations for an alloy or compound. The ability to selectively control microstructural stability and alter transformation kinetics through appropriate selection of the magnetic field strength promises to provide a very robust mechanism to develop and tailor enhanced microstructures (even nanostructures through accelerated kinetics) with superior properties for a broad spectrum of materials.

For this project, ferrous alloys were studied initially since this alloy family exhibits ferromagnetism over part of its temperature range of stability and therefore, would demonstrate the maximum impact of this novel processing mechanism. Additionally, for these ferrous alloys, the high-temperature parent phase, austenite, exhibits a significantly different magnetization response from the potential product phases, ferrite plus carbide or martensite, and therefore, the solid-state transformation behavior of these alloys will be dramatically influenced by the presence of ultrahigh magnetic fields. Finally, thermodynamic calculation capability was developed (within ThermoCalc™ for example) during this project to enable parametric studies to be performed to predict the magnitude of the influence of magnetic processing variables on the phase stability (phase diagrams) in ferromagnetic materials.



Prediction of the pseudobinary phase diagram for 1045 steel for both the conventional equilibrium (black lines) and magnetically enhanced (30T) equilibrium (blue lines) conditions

Benefits for Our Industry and Our Nation

Considering only the elimination of redundant normalization heat treatment of steels for bar and rod product to ensure no bainite is present during initial machining operations as a baseline to calculate the potential benefits of this program:

- *Annual cost savings of $91 million are possible*
- *Annual energy savings of 14 TBtu are possible*

Applications in Our Nation's Industry

Since all materials exhibit some form of ferromagnetism or paramagnetism, this program may show that magnetic processing can yield unique and novel microstructures with enhanced performance for a broad spectrum of materials impacting the following industries:

- Aluminum
- Chemicals
- Forging
- Heat Treating
- Metalcasting
- Steel
- Welding

Project Description

This research and development activity has the potential to develop a new potentially high-payoff industrial processing methodology whereby alloys and microstructures can be developed with superior properties that normally would be impossible to achieve with conventional thermomechanical processing techniques.

Barriers

- Conventional alloying, processing, and heat treating of materials is generally limited to the equilibrium microstructures that can be achieved as defined by a Temperature-Composition Phase Diagram or by some metastable microstructures observed and characterized in Continuous Cooling Transformation Diagrams that result from rapid cooling processes such that the equilibrium phases can not form
- Deformation processes may result in non-uniform distributions of the deformation strain throughout the bulk of the material which limits their usefulness in terms of reduced performance or frequent annealing cycles between deformation steps in a manufacturing environment

Pathways

There are two main objectives for this research endeavor. The principle objective is to evaluate magnetic processing as a viable and robust new technology for altering phase equilibria and phase transformation kinetics in a ferrous alloy with the goal of developing novel microstructures and properties unattainable through conventional thermomechanical processing approaches. The second objective is to develop the thermodynamic predictive capability that will include an evaluation of the influence of an applied magnetic field on the phase equilibria (stability as defined by Gibbs Free Energy and chemical potential) of ferrous alloys with the ability to extend this technique to more general ferromagnetic, paramagnetic, and diamagnetic materials.

Results

This project has successfully accomplished and significantly exceeded its goals. This effort has demonstrated and documented that ultrahigh magnetic field processing of ferromagentic materials:

- dramatically shifts phase equilibria and enhances phase solubilities,
- increases phase transformation kinetics,
- produces novel microstructures with enhanced performance, and
- provides a totally new and unique processing (thermomechanical-magnetic) methodology to design and engineer new materials and processing approaches.

Commercialization

This project was funded as a Laboratory Call Proposal under the IMF Program and so the goal was for ORNL researchers to develop a visionary concept to a stage where sufficient experimental data were available to substantiate future industrial participation in follow-on research and development efforts on specific industrial applications to commercialize this technology. The researchers on this project at ORNL are currently developing industrial interest, especially involving a superconducting magnet manufacturer, to pursue collaborations on relevant industrial applications of this magnetic processing technology. The goal is to have an informally organized industrial, university, and laboratory team ready to author and submit proposals to upcoming relevant solicitations that would provide research and development funding support for the next stage facilitating successful commercialization of this technology.

Project Partners

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Cummins, Inc.
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Florida State University
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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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