Research Programs

An Integrated Heat Treatment Model for Aluminum Castings

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Introduction

One of the most important research needs identified as a top priority by industry leaders at strategic planning workshops sponsored by the Department of Energy Office of Industrial Technology (DOE-OIT) is the development of integrated process models, the topic of the current research and development program. The goal is to change heat treating from an experience-based art to a process that is truly understood and capable of being simulated.

Objectives

The Objectives of the project are:

- Develop an enhanced, integrated computer model for the heat treatment of castings that includes thermal cycle, alloy composition, resultant microstructure, and final properties.
- Prepare a database for a selected Al alloy.
- Use the program to predict additional ways to recycle heat, eliminate re-heating where possible, and substantially reduce heating times.
- Use the program to design lower cost, heat treatable alloys.
- Predict the effect of accelerated heating on properties and show how rapid heating can be accomplished through furnace design.
- Develop an understanding of the relationship between Al alloy composition, processing, microstructure and properties. Experiments will be performed to test the validity of the integrated process model.
- Predict the temperature-time profile of parts in loaded furnace through modeling the heat transfer process in heating and quenching.
- Develop a method to optimize the heat treatment cycle time by optimizing the part load design and furnace temperature control while the quality is ensured.

Methodology

To achieve the objectives, the program is being managed under the auspices of the Center for Heat Treating Excellence (CHTE), a consortium of over fifty companies. The CHTE is a virtual center in that research is carried out at several universities and industrial sites, where the appropriate experience and facilities are located. Industry support and collaboration are being provided by an industry focus group that provides materials, testing, software, and specialized training. In addition they promote the transfer and commercialization of technology developed under this program in their company.

The plan is that the industry-university team will develop, verify and integrate their process modules for the heat treatment of aluminum castings. Then the modules will be transferred to industry to be further integrated with commercial casting simulation and casting design software packages. Databases for the thermo-physical and kinetic properties that enable the quantitative prediction of the evolution of microstructure and the attainment of specified strength, ductility, and fatigue properties in critical locations of aluminum castings will be developed from the literature and where necessary validated and extended by experiment. The methodology applied to the development of a model for aluminum castings can serve later as a framework to develop quantitative process models for other alloy systems, including ferrous alloys.

An integrated system of software, databases, and design rules will be developed, verified and marketed to enable quantitative prediction and optimization of the heat treatment of aluminum castings to increase quality and productivity, reduce the heat treatment cycle times and reduce energy consumption. The validated databases for multicomponent alloys and predictive models will enable comparable results to be achieved for a wide range of alloys and applications.

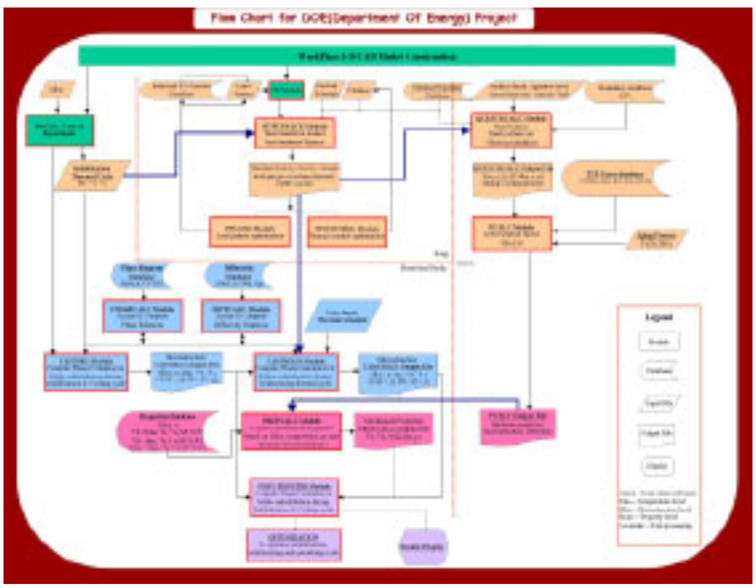

Figure 1. Flow chart for DOE project

The software will predict the thermal cycle in critical locations of individual components in a furnace, the evolution of microstructure, and the attainment of properties in heat treatable aluminum alloy castings. The model will take into account the prior casting process and the specific composition of the component. The heat treatment simulation modules will be designed to be used in conjunction with software packages for simulation of the casting process. The system will be built upon a quantitative understanding of the kinetics of microstructure evolution in complex multicomponent alloys, on a quantitative understanding of the interdependence of microstructure and properties, on validated kinetic and thermodynamic databases, and validated quantitative models.

Detailed understanding of the evolution of microstructure during the heat treatment together with accurate databases of experimentally determined thermodynamic and kinetic parameters will support quantitative predictive models for binary alloys, not for commercially important, multicomponent alloys. The research phases of this program will focus on gaps in understanding and data on multicomponent alloys --- to expand our understanding and ability to predict quantitatively (i) the kinetics of microstructure evolution and (ii) the relation of microstructure to strength, ductility, and fatigue properties. As the modules are developed and validated, their utility will be demonstrated as we apply the modules to meet three objectives: (i) reduced reheating, (ii) alloy design for faster response to heat treatment, and (iii) higher productivity.

Publications

1. L. He, J. Kang, T. Huang and Y. Rong, "Review on the Integrated Technique for the Heat Treatment of Aluminum Alloy Castings", Heat Treatment of Metals (accepted)
2. J. Kang, Y. Rong, W. Wang, "Numerical simulation of heat transfer in loaded heat treatment furnaces", Journal of Physics, Vol. 4, France, No. 120, 2004, pp. 545-553.
3. Y. Zhou, J. Kang, Y. Rong, F. Yi, H. Brody, "Integrated Numerical Simulation and Process Optimization for Aluminum Alloy Solutionizing", Heat Treat Theory & Innovation Program - Modeling Heat Treating Processes 2005 at the 23rd ASM Heat Treating Society Conference and Exposition, September 26-28, 2005 in Pittsburgh, PA.
4. R. Purushothaman, J. Kang, Y. Rong, "Application of Heat Treatment Modeling and Simulation, CHT-bf and CHT-cf", Heat Treat Theory & Innovation Program - Modeling Heat Treating Processes 2005 at the 23rd ASM Heat Treating Society Conference and Exposition, September 26-28, 2005 in Pittsburgh, PA.
5. X. M. Pan, C. Lin, J. E. Morral, H. D. Brody, "A Thermodynamic Database for the Al Rich Corner of the Al-Cu-Si System," Journal of Phase Equilibria and Diffusion (accepted).
6. Shuhui Ma, M. Maniruzzaman, Juan Chaves and R. D. Sisson, Jr., "Modeling of the effects of surface oxides on the quenching rates of 4140 steel in commercial mineral oils", The Materials Science & Technology + Heat Treatment Society 2005, Sep 25-28, 2005, Pittsburgh, PA.
7. Shuhui Ma, M. Maniruzzaman and R. D. Sisson, Jr., "Model Development of Quench Factor Analysis and Microstructure Prediction of Cast Al-Si-Mg Alloys ", The Materials Science & Technology + Heat Treatment Society 2005, Sep 25-28, 2005, Pittsburgh, PA.
8. Lin Lee, M. Maniruzzaman and R. D. Sisson, Jr., "The effect of flow rate and droplet distribution on spray quenching performance of 4140 steel and IVF probe in water", To be presented at the Materials Science & Technology + Heat Treatment Society 2005, Sep 25-28, 2005, Pittsburgh, PA.
9. Shuhui Ma, M. Maniruzzaman and R. D. Sisson, Jr., "Application of Jominy End Quench Approach for the Development of Quench Factor Analysis and Microstructure Prediction of Cast Al-Si-Mg alloys", To be presented at Solid-Solid Phase Transformations in Inorganic Materials 2005 (TMS), May 29~ June 3, 2005, Phoenix, Arizona.