Predicting the Response of Aluminum Casting Alloys to Heat Treatment

Research Team:

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Introduction

The mechanical properties of aluminum alloy castings can be greatly improved by a precipitation hardening heat treatment. Typically, this heat treatment consists of three steps: (1) solutionizing, (2) quenching, and (3) aging; and is performed by first heating the casting to and maintaining it at a temperature that is a few degrees lower than the solidus temperature of the alloy in order to form a single-phase solid solution. Then rapidly quenching the casting in a cold (or warm) fluid in order to form a supersaturated non-equilibrium solid solution; and finally, reheating the casting to a moderate temperature where nucleation and growth of the strengthening precipitate(s) can occur.

Obviously, these processing steps involve significant thermal changes that may be different from location to location within the casting. The objective of this project is to develop computer simulations based on a mathematical model and a comprehensive material database that allows predicting these physical and material property changes.

The commercially available finite element software ABAQUS[1] is being used in this work. This software can perform thermal-stress analysis such as calculating the distortion, residual stresses, and thermal profile across the casting due to heat treatment; however, it is not able to predict room temperature mechanical properties.

In Phase 1 (a recently completed ACRC project), a simpler model was developed and tested. The model used ABAQUS and a specially developed database that includes the necessary heat transfer coefficients (measured using the CHTE quenching system) and mechanical properties (measured using a Gleeble machine at the University of British Columbia). The model is shown in Fig. 1 and requires 3 inputs: the quenching heat transfer coefficient, the initial conditions, and the boundary conditions of the casting; and it produces 3 outputs at each node: the geometric distortion, the magnitude and type of residual stresses, and the thermal history.

[1] Hibbitt, Karlsson and Sorensen, Inc., RI, USA.

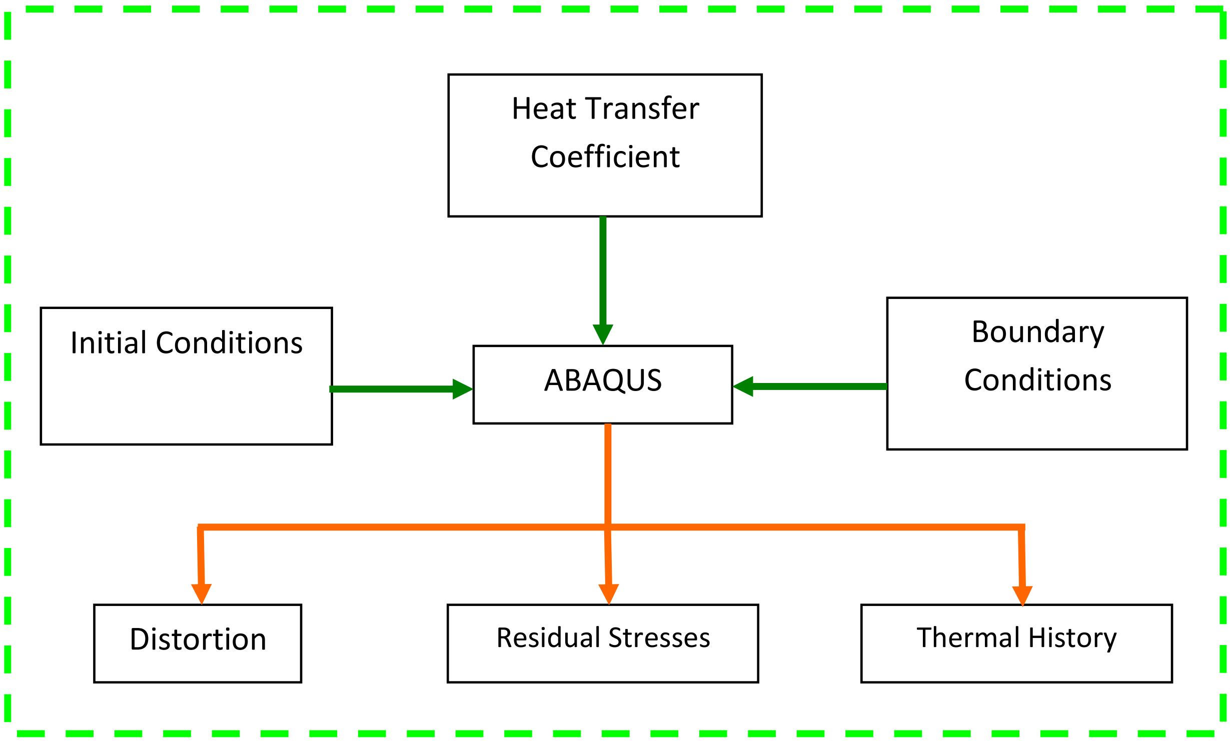


Fig. 1 Description of the Phase 1 Model.

In Phase 2 (the current project), the focus is on predicting the response of the casting to the aging step of the precipitation hardening heat treatment; i.e., the focus is on developing and adding to the Phase 1 Model a module and database for predicting the room temperature mechanical properties and hardness at each node within the model of the cast component.

The structure of the Phase 2 Model is described in Fig. 2 and builds on the model that was developed in Phase 1. In essence, output from the Phase 1 modules becomes input to the Phase 2 Module. That is, predicting distortion and residual stresses caused by the aging step will build upon the resultant distortion and residual stresses that develop in the solutionizing and quenching steps. Similarly, predicting the room temperature mechanical properties after aging will make use of the thermal history developed in the solutionizing, quenching and aging steps. This is being done by means of a Quench Factor Analysis.

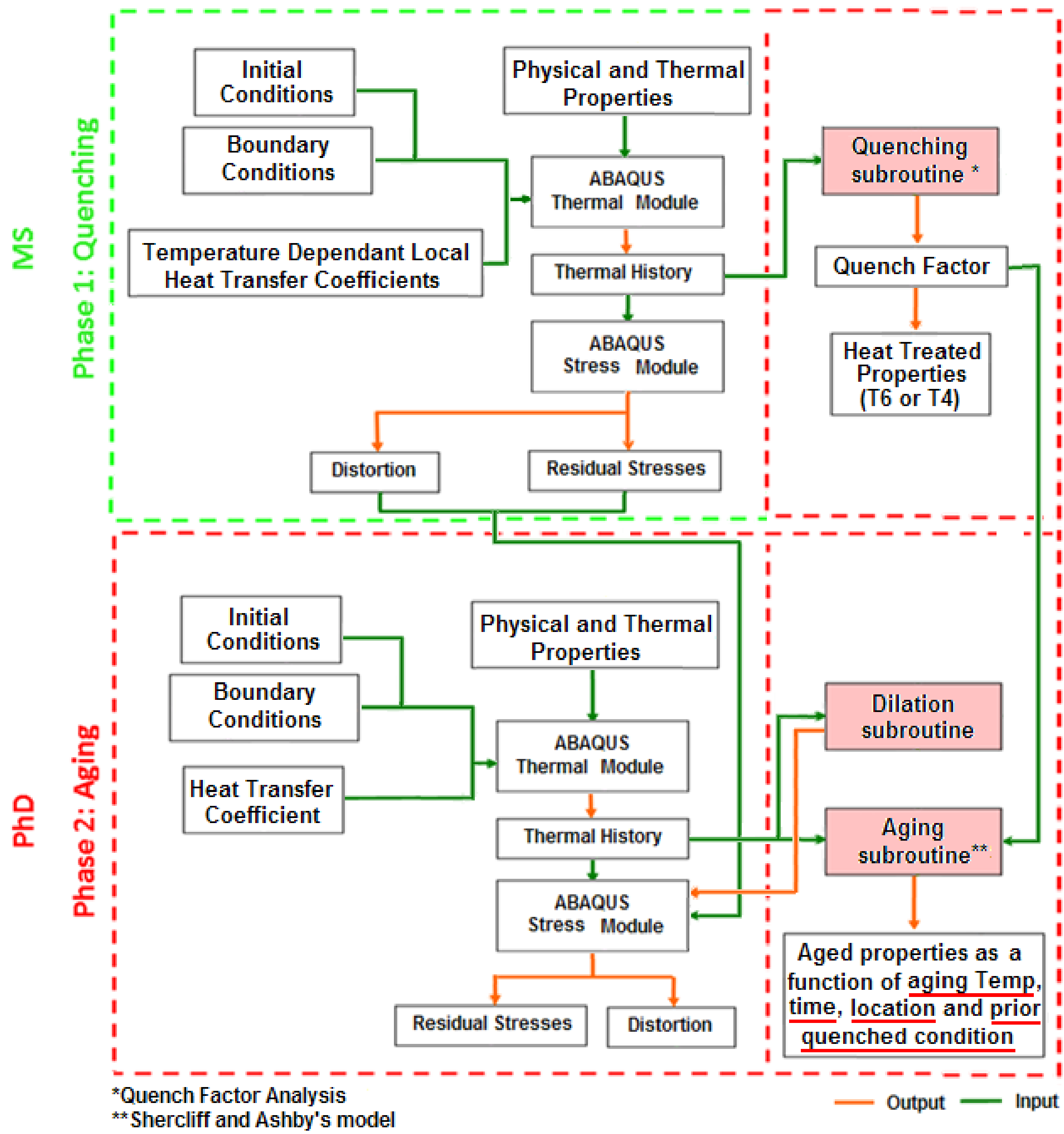


Fig. 2 Description of the Phase 2 Model.

Objectives

The objective of this project is to create a database and a computer model that allow predicting the effects of precipitation hardening heat treatment on the following characteristics of aluminum alloy castings:

- Distortion
- Residual stresses
- Room temperature mechanical properties; specifically,
  ultimate tensile stress,
  yield stress,
  hardness, and
  elongation

Methodology

The project is divided into five major tasks as follows:

Task 1: Improve the Phase 1 thermal module so that it predicts more accurate cooling rates

Subtask 1.1: Measure the thermal conductivity of A356.2 alloy as a function of temperature.

Subtask 1.2: Modify the quenching probe used for measuring the quenching heat transfer coefficients.

Subtask 1.3: Determine quenching heat transfer coefficients for complex castings (i.e. determine temperature-dependant local heat transfer coefficients).

Subtask 1.4: Verify the thermal module by simulating the heat treatment of a laboratory manufactured casting.

Task 2: Develop a QFA module for predicting surface hardness

Subtask 2.1: Develop the kinetics parameters and the Quench Factor Analysis for predicting surface hardness of heat treated castings.

Subtask 2.2: Introduce a subroutine in ABAQUS to include the Quench Factor Analysis for hardness.

Task 3: Expand the QFA module so that it predicts room temperature mechanical properties

Subtask 3.1: Develop the kinetics parameters and the QFA for predicting yield strength, ultimate tensile strength and ductility.

Subtask 3.2: Introduce a subroutine in ABAQUS to include the Quench Factor Analysis for room temperature mechanical properties.

Task 4: Develop an Integrated Heat Treatment Model

Subtask 4.1: Develop the Integrated Heat Treatment Model.

Subtask 4.2: Develop the aging data for A356.2 alloy.

Subtask 4.3: Determine the unknown parameters in the Shercliff-Ashby's aging model.

Subtask 4.4: Establish the modeling method and database for predicting ductility.

Subtask 4.5: Develop a module for predicting uniform dilation during aging.

Task 5: Verify the model predictions

Subtask 5.1: Validate the computer-predicted room temperature mechanical properties: Machine standard tensile test specimens from heat treated castings and measure their room temperature tensile yield strength, ultimate tensile strength, elongation, modulus of elasticity, and hardness.

Subtask 5.2: Validate computer-predicted dimensional changes and distortion: Use a Starrett coordinate measuring machine (CMM) to measure dimensional changes and distortion caused by the heat treatment process. Make sufficient measurements in order to obtain accurate representation of the part before and after heat treatment.

Subtask 5.3: Validate the computer-predicted residual stresses: Use the standard x-ray diffraction method for measuring residual stress in metallic components.

Salient Results

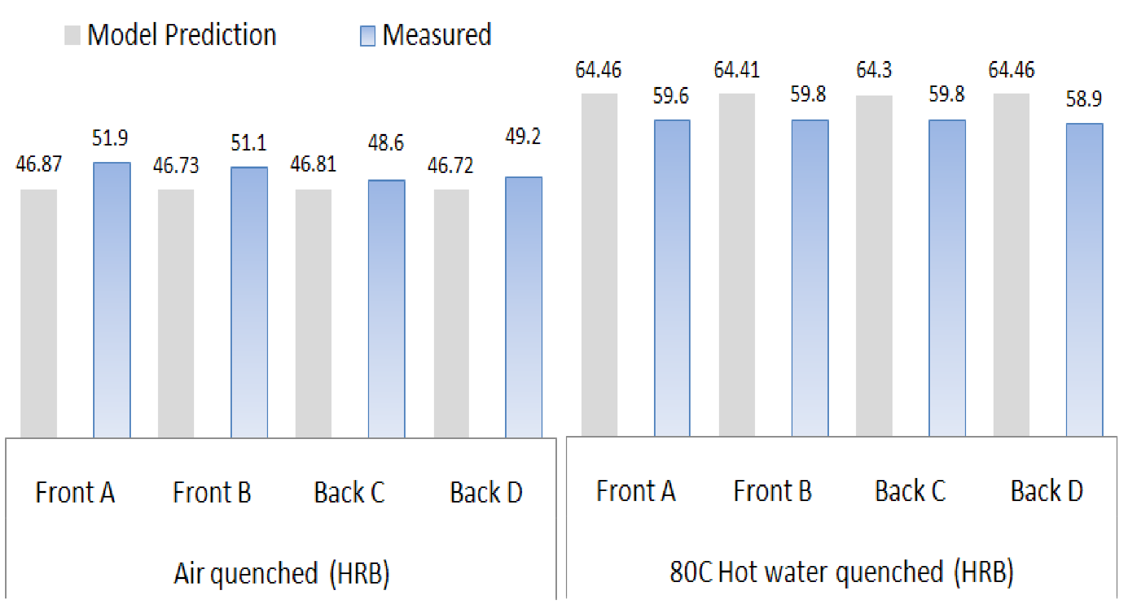
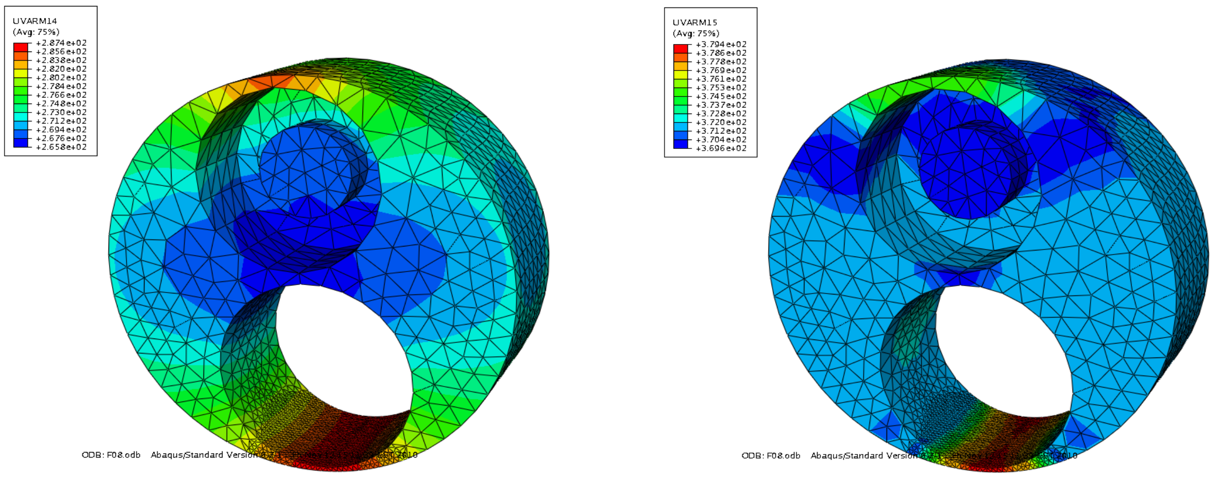
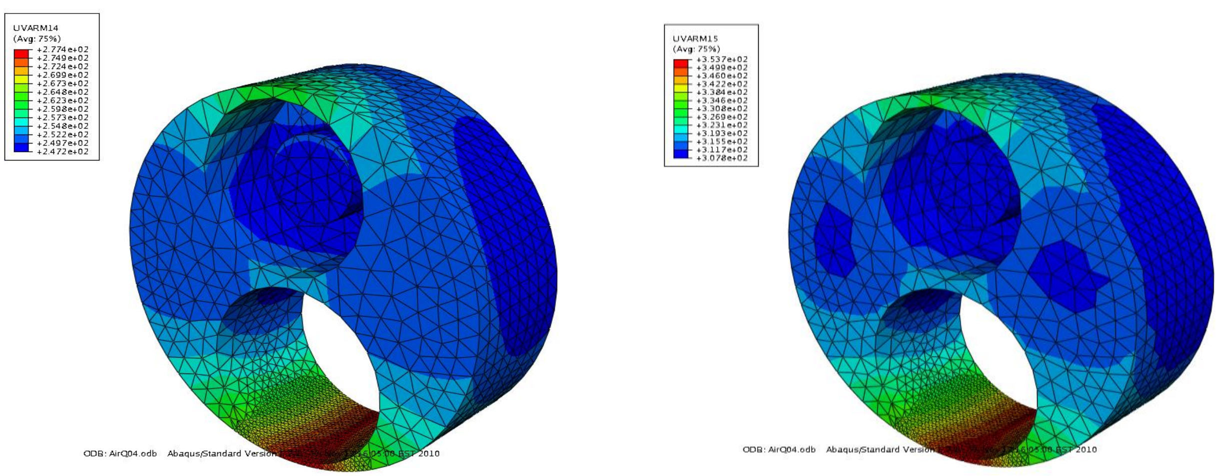


Fig. 3 Measured and computer-predicted hardness for water quenched and air quenched cast parts.



Yield strength (in MPa) ultimate tensile strength (in MPa)

Fig. 4 Computer-predicted properties of specimens quenched in hot (80➡C) water.



Yield strength (in MPa) ultimate tensile strength (in MPa)

Fig. 5 Computer-predicted properties of specimens quenched in forced air.