Multi-Physics Analysis of a Refractory Metal AC-Operated High Temperature Heater with Abaqus

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Abstract: Electrically operated high temperature furnaces and reactors are used in many industrial manufacturing processes such as sintering or single crystal growth in order to allow for the required process conditions. In view of their outstanding characteristics refractory metals are ideally suited as materials for the resistive heating elements. Nevertheless, significant and life-time-limiting irreversible deformations of these elements can be frequently observed which are assumed to be caused by a combination of temperature expansion, electromagnetic forces, and high temperature creep effects. In order to study this undesired behavior, a multi-physics model of a particular three-phase AC heating element of a sintering furnace is formulated and implemented within Abaqus. It accounts for the primary involved coupled physical mechanisms such as the harmonic electrical field problem, the thermal problem governed by Joule's law, thermal expansion, high temperature creep and harmonic forces caused by the electromagnetic field along with field dependent constitutive behavior. Since in general solving the fully coupled problem on a 3D domain is computationally demanding and Abaqus lacks functionality in the field of electromagnetism, a semi-analytical approach for consideration of time-harmonic electromagnetic forces within mechanical analysis is developed in the present work. The model implemented as a user-defined extension for Abaqus is computationally very attractive since it avoids discretization of the medium surrounding the heater. Furthermore, some aspects of modeling coupled physical problems of different characteristic time-scale are briefly discussed. Results from application of the model are in good qualitative agreement with in-situ observations and confirm the relevance of considering electromagnetic forces within analysis of high temperature furnaces.

Keywords: powder metallurgy, refractory metal, Tungsten, high temperature, resistive heater, three-phase, alternating current, AC, electromagnetic force, creep, multi-physics.

1. Introduction

Increasing demands with respect to functionality, durability, cost efficiency and sustainability increasingly affect almost all technical products. Both, industries with exceptionally high lead time in research and development as well as industries with pronounced time-to-market requirements are thus forced to optimize their technologies already at an early stage of development or even at a stage at which the product does not even physically exist. Prominent representatives are key technologies of the future such as the photovoltaic and LED technology, respectively. The latter are in particular driven by thermal processes for single crystal growth and in thin-film technology, respectively. High temperature furnaces and reactors with corresponding hot zones enclosing the operational space typically make use of refractory metal based heater elements and thermal