An Electro-chemo-mechanical Analysis of Solid Oxide Fuel Cell Considering Evolution of Microstructure in Porous Electrode Using Phase-field Method

M. Muramatsu*, S. Takase, K. Yashiro***, T. Kawada**** and K. Terada*******

* Graduate School of Environmental Studies
Tohoku University
468-1-404, Aoba, Aramaki, Aoba-ku, Sendai 980-0845 Japan
e-mail: muramatsu@ee.mech.tohoku.ac.jp

** Department of Civil and Environmental Engineering
Tohoku University
468-1-404, Aoba, Aramaki, Aoba-ku, Sendai 980-0845 Japan
e-mail: takase@irides.tohoku.ac.jp

*** Graduate School of Environmental Studies
Tohoku University
6-6-01, Aoba, Aramaki, Aoba-ku, Sendai 980-8579 Japan
e-mail: yashiro@ee.mech.tohoku.ac.jp

**** Graduate School of Environmental Studies
Tohoku University
6-6-01, Aoba, Aramaki, Aoba-ku, Sendai 980-8579 Japan
e-mail: kawada@ee.mech.tohoku.ac.jp

***** International Research Institute of Disaster Science
Tohoku University
468-1-404, Aoba, Aramaki, Aoba-ku, Sendai 980-0845 Japan
e-mail: tei@irides.tohoku.ac.jp

ABSTRACT

Components of Solid Oxide Fuel Cells (SOFCs) are always exposed to high temperature and large gas pressure under operation. Subjected to the starting and stopping control, the performance of SOFC is gradually degraded. One of the degradation factors can be the thermal expansive deformation due to temperature change, but the expansive deformation under reduction environment is distinguishing for SOFC. These stress-free deformations inevitably invoke the unexpectedly large stress due to the mutual constraints of the components, which sometimes causes the mechanical deterioration. At the same time, Ni particles in the porous anode electrode of SOFC are subjected to coursing due to sintering under high temperature environment. The temporal changes of the anode microstructures cause the degradation of not only the overall mechanical properties, but also the electrical performance.

In order to realize the macroscopic electro-chemo-mechanical coupling analyses of a SOFC under operation, we propose a characterization method of the time-varying overall or macroscopic electro-chemical and mechanical properties of anode electrodes by applying the phase-field method that enables us to capture the time-varying geometry of anode microstructures due to Ni-sintering. With this information at hand, the homogenization method is extensively applied to evaluate the temporal change of the macroscopic electro-chemo-mechanical properties that characterize the macroscopic inelastic mechanical behaviour and the oxygen potential distribution in SOFC.

For the numerical simulation of oxygen potential distributions, the time-evolution of the anode microstructure is reflected not only in the macroscopic electrical conductivities, but also the amount of triple-phase boundaries, which are the generation sites of electro-chemical reaction currents. Once the oxygen potential distributions are determined, the time-variation of the reduction-induced strains due to nonstoichiometry of oxide materials can be calculated along with the thermal strains, both of which cause the macroscopic stresses in mutually constrained components. Thus, the promise and capability of the proposed method can be demonstrated in characterizing the aging degradation of the macroscopic electro-chemo-mechanical behaviour of SOFC that is caused by the Ni-sintering in cermet microstructures during long-period control.