FINITE ELEMENT ANALYSIS OF HOT SPOTS IN FLASH SINTERING

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Sintering inhomogeneities due to the formation of hot spots in flash sintered materials constitute a major hindrance to the scaling up of the technique to industrial level. Although the exact microstructure mechanisms that govern the flash are not yet fully understood, it is important to address the hot spot issue at this stage already. Dong proposed theoretical criteria for the onset of the thermal runaway [1] and the development of hot spots [2] in two papers. These studies, however, rely on analytical developments made tractable by simplifying assumptions (e.g., the hot spot spatial distribution is assumed perfectly sinusoidal). In this paper, we build up on this analysis, but lift several simplifying of the assumptions of the analytic approach by using specific finite element simulations. The proposed transient 2D model solves the unstable thermal field in a sample subjected to a user-defined electric field perpendicular to the domain of analysis, assuming an Arrhenius-like dependency of the electric conductivity on temperature, and no field variation in the direction parallel to the applied field. Convective or radiative boundary condition are applied on the lateral side of the sample. Densification is not considered. The model can resolve the development of in-plane inhomogeneous distribution of the current density, Fig.1 (Right). Thanks to a temperature-controlled adaptive time step, the unstable thermal field is simulated throughout the incubation phase up to the thermal runaway, ensuring that the energy balance is accurately respected at each time. Slightly inhomogeneous initial temperature fields are applied to nucleate hot spots and introduce in the modelling the effect of inhomogeneities like, e.g., an imperfect sample/electrode contact. This model is useful to (i) assess the risk of developing hot spots in function of the conditions of the experiment (sample dimensions, current/voltage source, oven), and (ii) to characterise quantitatively the rates at which they develop in space and time.

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[1] Y. Dong and I.-Wei Chen, Predicting the Onset of Flash Sintering, J. Am. Ceram. Soc., 98 [8] (2015) 2333–2335, DOI: 10.1111/jace.13679
[2] Y. Dong, On the Hotspot Problem in Flash Sintering, http://arxiv.org/abs/1702.05565 (2017)

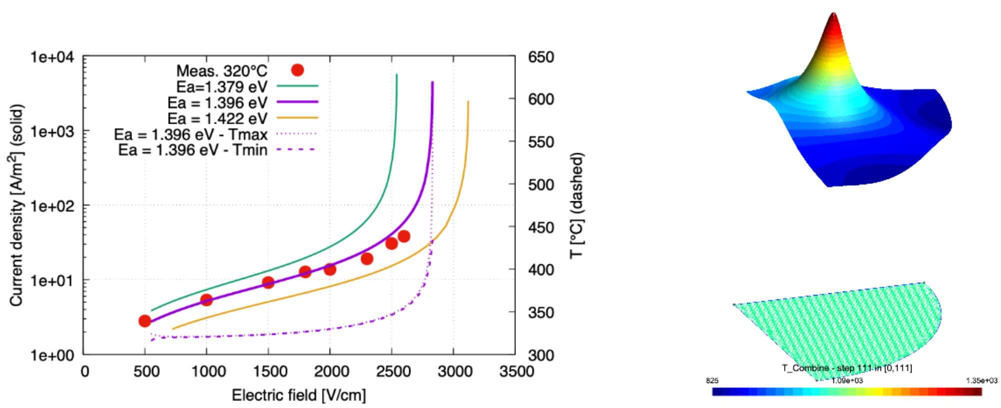

Fig. 1. Left: Model validation against measurements for a small cylindrical YSZ sample (diam=10mm) in an oven at 320°C. The effect of changing the activation energy in the Arrhenius conductivity law (pre-exp. Factor: 3.65 10^7 S/m), and min/max temperature in the sample are also shown. Right: Developed hot spot in a larger cylindrical YSZ sample (diam=50mm, 1/4th of the sample is modeled) in an oven at 700°C with an applied ramp of electric field of 5+t V/cm, where t is the time in second. The expected spot radius according to [2] is 15mm in this case.