Coupled Discrete Element Model for Thermal-Electrical-Mechanical Phenomena in Spark Plasma Sintering

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ABSTRACT

Spark Plasma Sintering (SPS) is a powder consolidation process that combines mechanical pressure with rapid Joule heating induced by electric current. This facilitates the consolidation and densification of particulate materials, making SPS a sustainable and energy-efficient technique. Initially, the powder consists of loosely bonded particles. As the process progresses, the particles become connected through necks, which grow over time due to diffusion and mass transport. The complexity of the SPS process lies in the strong interdependence of electrical, thermal and mechanical phenomena. Accurate modelling of this process requires a fully coupled multiphysics approach.

In this work, a microscopic thermo-electro-mechanical model is developed within the Discrete Element Method (DEM) framework. DEM allows microscopic analysis by treating each particle as a discrete element, allowing precise representation of microscopic interactions. The model is based on sintering geometry assuming cylindrical neck formation between spherical particles. Individual models for electrical, thermal, and mechanical behaviour are first validated separately, and then integrated into a fully coupled model. Thermal and electrical models were presented in [1, 2], where effective properties were evaluated and validated using experimental measurements. Coupled thermo-electric model was presented in [3], where it was shown that Joule heating – generated due to current flow – tends to concentrate in smaller particles but is effectively conducted throughout the sample, leading to a relatively uniform temperature rise. Finally, the effect of densification on heating rate was analysed. Herein, the coupled thermo-electric model will be integrated with the mechanical model to study the multiphysics phenomena during the SPS process.

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