

Werkstoffanwendungen im Maschinenbau

Band 21

Sree Koundinya Sistla

Numerical Modelling and Simulation of Temperature Fields, Densification and Grain Growth during Field Assisted Sintering Technology



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Numerical Modelling and Simulation of Temperature Fields, Densification and Grain Growth during Field Assisted Sintering Technology

Numerische Modellierung und Simulation von Temperaturfeldern, Verdichtung und Kornwachstum beim feldunterstützten Sintern

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Abstract

Field Assisted Sintering Technology, also known as Spark Plasma Sintering (FAST/SPS), is a new innovative sintering and synthesis technique. Due to the way electrical current flows through a tool system, high heating rates and short cooling periods are achieved. With assistance from the application of external pressure, it enables the drastic reduction of the sintering time, thereby reducing the production time and improving the microstructure and material properties. Finite Element Method (FEM) has been proven to be the best numerical tool to visualize the FAST/SPS process, and numerous modelling methods have been proposed in the literature. Although detailed modelling procedures are available, certain physical aspects have been neglected, such as the effect of electrical field/current on the microstructure evolution during sintering.

In this work, a Multiphysics FEM model has been developed to investigate the sintering of a broad spectrum of materials. Gadolinium doped ceria (GDC) has been chosen as oxide ceramic material due to its high electrochemical activity and stainless steel 316L (SS 316L) because of its simplicity in understanding the sintering mechanisms. The sintering kinetics were studied in detail, and sintering mechanisms for both materials have been proposed.

At elevated temperatures and dwell periods, the GDC samples exhibited the development of asymmetrical microstructures even under low electrical fields ($< 5 \text{ V/cm}$). This effect has been observed for the first time. Enhanced grain growth was observed at the anode region, and this was attributed to the migration of oxygen ions under an electrical field to the anode, which led to high grain boundary mobility in that region. This experimental observation was also successfully modeled, with the simulations showing accurate results. Furthermore, the modelling procedure was also verified by using the other class of material, SS 316L. In this case, the effect of pressure on sintering was studied and numerically verified. Towards the end of the work, to validate the modelling procedure, simulations were carried out to simulate the sintering process of complex shaped geometries. The validation was realized by simulating the FAST/SPS of a SS 316L. The simulation was carried out by implementing a closed-loop control system (Proportional-Integral-Derivative (PID) controller) in the FEM simulation, which made the models independent of FAST/SPS experiments.

Zusammenfassung

Feldunterstütztes Sintern/Spark Plasma Sintern (FAST/SPS) ist ein modernes innovatives Sinter- und Syntheseverfahren. Aufgrund der Art des elektrischen Stromflusses durch ein Werkzeugsystem, werden hohe Aufheizraten und kurze Abkühlzeiten realisiert. Die Anwendung von externem Druck ermöglicht die drastische Verkürzung der Sinterzeit, wodurch die Produktionsdauer verkürzt und die Materialeigenschaften verbessert werden. Die Finite-Elemente-Methode (FEM) hat sich als das beste numerische Werkzeug zur Visualisierung des FAST/SPS-Prozesses erwiesen, und in der Literatur wurden zahlreiche Modellierungsmethoden entwickelt. Obwohl detaillierte Modellierungsverfahren zur Verfügung stehen, werden bisher bestimmte physikalische Aspekte in der Simulation vernachlässigt. So wurde z.B. über den Einfluss des elektrischen Felds/Stroms auf die Mikrostrukturentwicklung während des Sinterns, nicht berichtet und diese nicht vollständig verstanden.

In dieser Arbeit wurde ein Multi Physics-FEM-Modell entwickelt, um das Sintern von unterschiedlichen Werkstoffgruppen zu untersuchen. Gadolinium-dotiertes Ceroxid (GDC) wurde aufgrund seiner hohen elektrochemischen Aktivität als oxidkeramische Werkstoff und ein austenitischer korrosionsbeständiger Stahl 316L (SS 316L) als metallischer Werkstoff ausgewählt. Im Rahmen dieser Arbeit wurden FAST/SPS-Experimente durchgeführt und die gesinterten Proben charakterisiert, um Modelle zur Abbildung der Sinterkinetik (Verdichtung und Kornwachstum) zu ermitteln.

Nach bestem Wissen des Autors zeigten die GDC-Proben zum ersten Mal bei erhöhten Temperaturen und Haltezeiten die Entwicklung einer asymmetrischen Mikrostruktur auch bei geringen elektrischen Feldern (< 5 V/cm). Es wurde ein stärkeres Kornwachstum im Anodenbereich beobachtet, was auf die Migration von Sauerstoff-Ionen zur Anode unter einem elektrischen Feld zurückgeführt wurde. Diese experimentellen Beobachtungen wurden erfolgreich modelliert, wobei die Simulationen genaue Ergebnisse zeigten. Darüber hinaus wurde das Modellierungsverfahren auch unter Verwendung der anderen Werkstoffgruppe, SS 316L, verifiziert. In diesem Fall wurde die Auswirkung des Drucks auf das Sinterverhalten untersucht und numerisch verifiziert. Gegen Ende der Arbeit wurden zur Validierung des Modellierungsverfahrens Simulationen des Sinterprozesses von komplex geformten Geometrien durchgeführt. Dies wurde durch die Simulation des Sinterns eines Zahnrades aus SS 316L realisiert. Die Simulation wurde durch die Implementierung eines geschlossenen Regelkreises (Proportional-Integral-Derivativ-Regler) in die FEM-Simulation durchgeführt, wodurch die Modelle unabhängig von FAST/SPS-Experimenten wurden.

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