論文 / 著書情報
Article / Book Information

題目(和文)	微構造の3次元可視化による焼結の熱力学的駆動力の解明
Title(English)	Clarification of thermodynamic driving force for sinteringfrom 3-D visualization of the microstructure
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	材料 材料	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（ 工学 ）
学生氏名： Student's Name	大熊 学		指導教員（主）： Academic Supervisor(main)	若井史博	
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Sintering is a common process during which nanoparticles and microparticles are bonded, leading to the shrinkage of interstitial pore space. Understanding morphological evolution during sintering is a challenge, because pore structures are elusive and very complex. A topological model of sintering is presented here, providing insight for understanding 3-D microstructures observed by X-ray microtomography. Three stages of sintering are distinguished by using Euler characteristics, which is given as the number of closed pores minus the genus. The random packing of particles is expressed as vertices, edges, faces, and cells topologically. The genus is the number of holes, which is equivalent to the number of pore channels connecting voids inside each cell. The elementary processes in morphological transformation of pore structure is the creation and annihilation of pore channels and those of closed pores. Although the Euler characteristic vs relative density curve was studied only for viscous sintering of silicate glass particles here, I believe the result is general and may explain the sintering behavior of many ceramic and metallic particles. These results may open the way to control internal defects formed during sintering, because it is crucial to understand the evolution of heterogeneous pore structures for improving the mechanical reliability of products. The interfacial topology provides a description of stages of sintering, and the foundations to identify the range of applicability of the methods for determining the sintering stress, that is the thermodynamic driving force of sintering.

Sintering stress and bulk viscosity of spherical soda lime glass were derived as functions of relative density from microtomographic images in viscous sintering of glass particles. In the initial stage of sintering, the sintering stress is estimated from the sintering force acting among particles. The mixed method gives fairly good estimate of sintering stress in the initial and the intermediate states. The surface energy method is valid in the final stage of sintering. I have demonstrated also that the sintering stress obtained by the surface energy method depends on the pore size distribution. The decrease of sintering stress in the final stage results from pore coarsening. The sintering stress is the driving force for shrinkage, but can generate internal tensile stress when the shrinkage of the sample is constrained. The presence of internal stress is the origin of microstructural instability, so that pore coarsening occurs in the constrained sintering. Overall, we have demonstrated the feasibility of combining microtomographic images with constitutive parameters to predict the sintering behaviors of specific powder compacts. This approach can be applied to study the relationship between powder processing and sintering mechanics from the point of view of the nature of initial particle packing.

Sintering stress and bulk viscosity of CAS glass were also measured by the discontinuous sinter forging experiment for comparison with experimental values from the microstructural evolution during viscous sintering of spherical soda lime glass particles by X-ray microtomography. The bulk viscosity and shear viscosity increased with increasing relative density. The sintering stress increased with relative density. The decrease of sintering stress in the final stage, which had been reported during sintering of crystalline particles, was not observed in viscous sintering. Even though the initial particle size and chemical composition of glass particles were different, both techniques provided consistent and reliable values when the bulk viscosity was normalized by the viscosity of glass and the sintering stress was normalized by the surface tension and the initial particle size.

Lastly, The continuum mechanics is normally concerned with the behavior of matter on a macroscopic scale that is large compared with discrete particles. However, although there is general agreement on the need for a unified treatment of continuous media, there is no agreement as to the proper level at which this unification should take place. I introduce the concept of the representative volume element (RVE), which is a volume that is sufficiently large to contain enough information at the micro scale in order to be representative, but it should be much smaller than the macroscopic body. The macroscopic properties in heterogeneous materials are defined as the average over the RVE. The minimum size of RVE was defined as the edge length of cubic volume elements above which the heterogeneity no longer affected the standard deviation. The RVE size was estimated to be from 11 to 17 times larger than the average initial particle size. Alternatively the RVE size was defined from the value of normalized standard deviation. The RVE size increased when the desired accuracy was higher. The RVE size was dependent on relative density, and varied with microstructural evolution. The relationship between RVE size and relative density was dependent on the physical property of interest.