Flash Sintering of Ceramics: Thermal Runaway and Ultrafast Firing

Richard TODD[(1)], Eugenio ZAPATA SOLVAS[(1,5)], Simone FALCO[(2)], Barnaby PARKER[(1)], Sebastian BONILLA[(1)], Michiyuki YOSHIDA[(1,3)], Wei JI[(1,4)], Jinyong ZHANG[(4)], Zhengyi FU[(4)]

[1]Department of Materials, University of Oxford, United Kingdom
[2] Department of Engineering Science, University of Oxford, United Kingdom
[3]Deptartment of Chemistry and Biomolecular Science, Gifu University, Japan
[4]State Key Lab of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, P.R. China
[5]University of Seville, Spain

"Flash sintering" refers to the rapid densification of ceramics at low furnace temperatures by passage of an electric current and was first reported by Raj and co-workers in 2010 using the ionic conductor 3 mol% yttria stabilised zirconia (3YSZ). Since then it has been demonstrated in many other ceramics, including covalent semiconductors, electronically conducting oxides and whitewares. The low furnace temperatures, rapid turnaround times and possibilities of producing novel microstructures offer significant commercial advantages but controlling the process is essential as severe localisation of the temperature can occur under some conditions. In order to do this, the process needs to be understood so that that predictive process models can be developed.

The presentation begins with a description of flash sintering, illustrated using 3YSZ. It is shown that the thermal and electrical response during the flash event can be explained and modelled well in terms of classical thermal runaway of Joule heating resulting from the negative temperature coefficient of resistivity exhibited by most ceramics under the relevant conditions of high temperature and electric field.

The second part of the presentation discusses the origin of the rapid sintering observed. Although it is clear that the electrical heating of the specimen raises its temperature well above that of the furnace, it is concluded that the specimen temperatures experienced during flash sintering are not sufficient to explain the rapid sintering by naïve extrapolations of conventional sintering based on a single Arrhenius expression. Experiments are described in which powder compacts are heated and cooled with a temperature profile similar to that of flash sintering but without the application of an electric field. This is achieved by enclosing the 3YSZ powder compacts in mixtures of powders which undergo a self-sustaining exothermic reaction when ignited. The results show a significant acceleration in sintering rate compared with extrapolations from conventional sintering but without the action of electricity. It is concluded that the rapid heating in flash sintering rather than the electric current responsible for it is responsible for much of the acceleration of sintering observed. Possible explanations for this "ultra-fast firing effect" are discussed.