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Introduction

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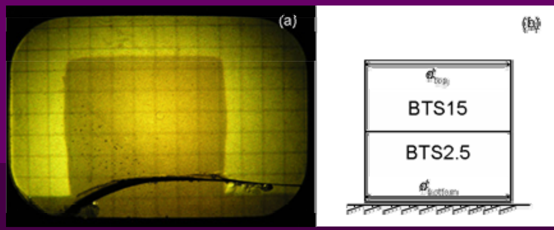
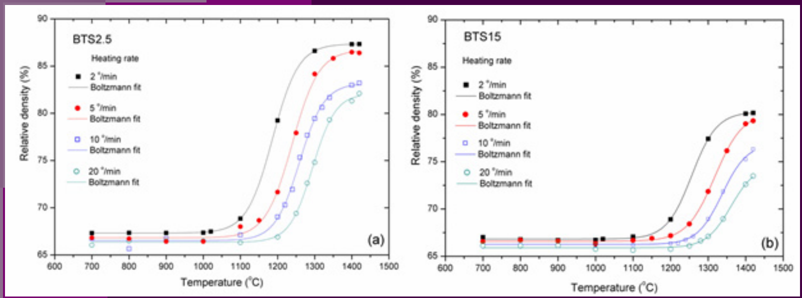
The most important aim in the design and processing of functionally graded materials (FGMs) is to produce devices free from any deformation. Smart choices of different combination of graded layers, as well as the heating rate during sintering, are important for the fabrication of high-quality FGMs. Here, $BaTi_{0.975}Sn_{0.025}O_3/BaTi_{0.85}Sn_{0.15}O_3$ (noted as BTS2.5 and BTS15, respectively) FGM was used as a model system for the construction of master sintering curves (MSCs) and estimation of sintering activation energies for different BTS graded layers. The MSCs were constructed, for BTS2.5 and BTS15 graded layers in FGMs, using shrinkage data obtained by a heating microscope during sintering at four constant heating rates, 2, 5, 10 and 20 °/min. The activation energies were determined using the concept of MSC; values of 359.5 and 340.5 kJ/mol were obtained for graded layers BTS2.5 and BTS15, respectively. A small difference of activation energies of chosen powders made it possible for us to prepare high-quality FGMs, without delamination, distortion or other forms of defects.



(a) Photograph of sintered cylindrical sample as observed in heating microscope
(b) Scheme of uni-axially pressed layered sample (after sintering denoted as BTS FGM) with marked diameters measured during sintering.

MSCs for BTS FGMs



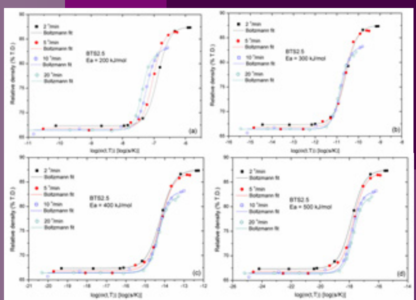
Relative density (% TD) *versus* temperature for: (a) graded layer BTS2.5 and (b) graded layer BTS15, in BTS2.5/BTS15 FGMs

The relative density was converted from the shrinkage values using the relation

$$\rho = [1/(1 - dl/l_o)]^3 \rho_o$$

l and l_o - the initial value of diameter l_o at time t_o and the value of d_i at time t_i
ρ and ρ_o - the densities of the sintered and the green layer, respectively

Estimation of activation energies for graded layers BTS2.5 and BTS15 in BTS2.5/BTS15 FGM



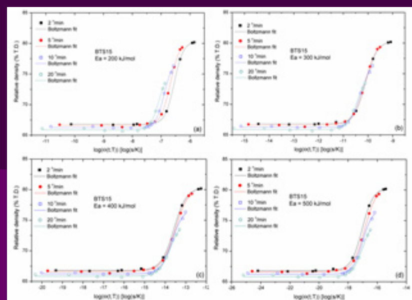
$\Phi(\rho)=\log\Theta(t,T(t))$ for different Ea, for graded layer BTS2.5

$$\Theta(t,T(t)) \equiv \frac{1}{c}\int_{T_o}^{T}\frac{1}{T}\exp\left(-\frac{E_a}{RT}\right)dT$$

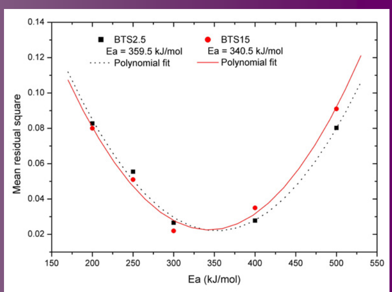
c - the heating rate
T_o - the temperature below which no sintering take place

The relationship between the density (ρ) and Θ is defined as the MSC

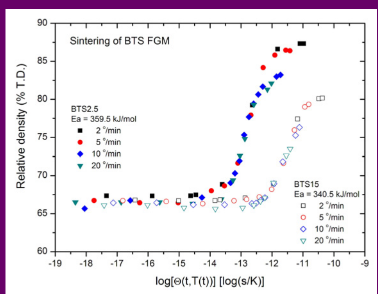
$$\Phi(\rho) = \Theta(t, T(t))$$



$\Phi(\rho)=\log\Theta(t,T(t))$ for different Ea, for graded layer BTS15



Mean residual square *versus* Ea for graded layers BTS2.5 and BTS15 in BTS2.5/BTS15 FGM



MSC ($\Phi(\rho)=\log\Theta(t,T(t))$) for BTS2.5 and BTS15 graded layers in BTS2.5/BTS15 FGM

Conclusions

Conclusions

The master sintering curves for BTS2.5 and BTS15 graded layers in FGMs were constructed using the shrinkage data obtained by heating microscope. The concept of MSC has been used to estimate the activation energy for sintering for the above composition of FGM, the values of 359.5 and 340.5 kJ/mol were obtained. Those values of activation energy indicate more than one mechanism of mass transport, which simultaneously occur during the sintering process of BTS2.5/BTS15 FGMs. Neglecting differences between the activation energies of BTS2.5 and BTS15 graded layers enable the production of FGMs free of any form of deformation during sintering up to 1420 °C.