Numerical modelling of sintering and thermal damage in a non-densifying refractory ceramic

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Abstract

High performance refractory ceramics for the glass industry are designed to resist the extreme thermal, chemical (corrosion) and thermomechanical conditions of glass furnaces operations. Experiments can be performed at the lab scale to study the properties of such materials and improve their performance and durability. However, for industrial purposes, it is of interest to transfer the findings to larger scales, and numerical modeling is an essential tool to achieve this. In this work, a phenomenological model of the two main physical processes occurring in an alumina mullite zirconia refractory during high temperature thermal cycles, namely sintering and thermal damage, is proposed.

In classical sintering models, the density of the material is followed throughout a temperature cycle and provides information on the progress of sintering along the cycle (1-3). However, the global shrinkage of the studied material is negligible, and density is therefore not a good indicator for sintering. That is why a different approach was used, based on the dynamic elastic modulus, which is measured during a thermal cycle and assumed to be a relevant parameter for characterizing sintering progress during heating and early cooling. The same approach was used to model thermal damage, i.e., assuming that the variation of the dynamic elastic modulus during late cooling is a good indicator of damage state. Sintering and damage rates were described with evolution laws and the model was calibrated to properly describe the behavior of the refractory during a thermal cycle up to 1350◦C, 10h dwell time and heating and cooling ramps of 200◦C/h. The relevance of the model was then analyzed by applying it to other thermal treatments. The model accurately predicts the evolution of the dynamic HMOE for thermal cycles with different sintering temperatures and it provides the variation of the associated sintering and damage degrees.

In order to demonstrate the industrial interest and applicability of the model, the case study of a brick under a thermal gradient is presented. For this purpose, a thermal gradient test was developed experimentally, and the corresponding numerical model was implemented on COMSOL. The hardness was finally used as a sintering indicator to confront the numerical and the experimental results.

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