Modeling the link between microstructure, thermomechanical treatment and mechanical performance of refractory products

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Jury :

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Abstract: Carbon-bonded alumina refractories are heterogeneous and complex granular composites made of coarse alumina, graphite pellets, and a bonding matrix (mixture of fine alumina grains and binder). These composites are used for steel casting applications. The final refractory properties are governed both by the properties of the components and by the processing stages (mixing, compaction, and firing). Depending on the final shape of the industrial part, the powder composite may be compacted isostatically or uniaxially. The compaction may lead to density gradients along the geometry resulting in thermo-mechanical properties mismatch and, consequently, stress concentration and failure during the firing process. Efforts have been devoted to modeling the constitutive compaction behavior of refractory industrial parts by the Finite Element Method (FEM) using elastoplastic models. However, the material parameters of such models need to be identified by complex experiments. The Discrete Element Method (DEM) may be an alternative to provide such parameters. The DEM can model the compaction stage and the compacted composite final mechanical properties by explicitly taking into account the discrete nature of the powder. Also, DEM may be applied to generate constitutive equations to simulate the compaction at the macro scale using the FEM. In this work, we develop a numerical model based on the DEM to simulate the compaction behavior of powder composites and their mechanical properties after compaction and firing. It is based on X-ray tomography observations and experimental data originating from compaction and triaxial tests. The mechanical input parameters of the DEM are calibrated on experimental compaction data. Four different composites in DEM are represented as a mixture of single particles (fine alumina), particle clusters (coarse alumina and graphite) with various volume fractions. The binder is represented by a soft elastic shell covering hard coarse/fine alumina particles. The densification behavior during compaction and the green properties depend mostly on the contact between those coated particles. The compacted numerical samples are submitted to various complex stress state

conditions to generate yield and fracture surfaces fitted with the elastoplastic Drucker-Prager Cap model (DPC). Following the compaction, the compacted numerical samples are virtually fired in DEM, and their mechanical and fracture behavior is presented. The compaction, green, and after-firing mechanical behavior are compared with experimental data. The results are in good agreement both qualitatively and quantitatively. In particular, the simulations capture the softening effect of an increasing amount of binder. Finally, an attempt to model the composite compaction behavior in a rigid die using the FEM is presented. It uses the DPC model with the material parameters identified by DEM. This model may be used in the future for the compaction of industrial pieces.