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Hybrid Constitutive Law with Machine Learning for Sintering of Advanced Ceramics

Predictive simulation of sintering-induced distortion remains challenging for ceramic components subjected to gravity and mechanical constraint. Classical constitutive sintering laws reproduce free densification reliably but lack the flexibility required to capture stress-driven deformation within finite-element (FE) frameworks when calibrated solely from dilatometer data. This study presents a hybrid machine-learning-assisted constitutive framework for modelling constrained sintering of an industrial ceramic material. Dilatometer densification data and a gravity-loaded beam-bending experiment were obtained for the same material system, enabling assessment of volumetric sintering kinetics and part-level deformation. Two independently calibrated parameter sets of an Olevsky-type constitutive law reproduce densification behaviour but underpredict gravity-driven curvature when applied in FE simulations, highlighting a trade-off between densification fitting and deformation prediction. To overcome this limitation, the analytical volumetric strain-rate term is replaced by an artificial neural network trained directly on experimental densification data, while analytical formulations for mean and deviatoric stress response are retained. The hybrid framework enables improved prediction of constrained sintering deformation without compromising physical interpretability or numerical robustness, providing a basis for industrial process optimisation and future digital-twin development.

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No

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