Influence of boundary conditions on the response of porous unit cells with random void arrangements

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The study investigates how the predicted mechanical response of porous ductile solids depends on the choice of boundary conditions and the spatial arrangement of voids in finite element unit-cell models. Two-dimensional plane-strain unit cells with randomly distributed spherical voids were analyzed using both periodic boundary conditions (PBC) and kinematically uniform boundary conditions (KUBC). Two void population sizes were considered (5 and 25 voids) for a fixed porosity, and several void samples were generated for each population size, each corresponding to a unique Statistical Volume Element (SVE). Each of the SVEs were subjected to several macroscopic stress states governed by various ratios between the in-plane macroscopic stress components. In addition to the role of boundary conditions for the numerical predictions of macroscopic behavior, the study evaluates whether spatial clustering descriptors can be used to predict the failure strain more effectively than porosity or average void spacing alone.

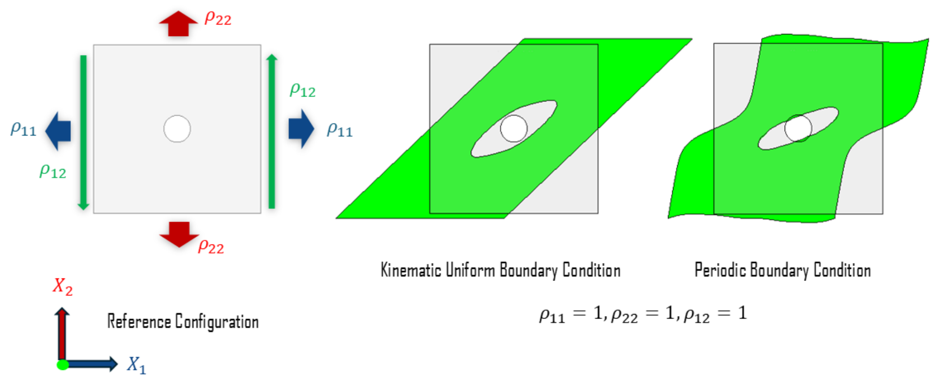

Figure 1: Illustration of boundary conditions.

The results show that the predicted failure strain depends strongly on the imposed stress state, the boundary conditions, and the spatial distribution of voids. A systematic difference is observed between the two boundary-condition choices, with KUBC consistently predicting higher stress levels and larger failure strains than PBC because the more restrictive kinematic constraints suppress deformation modes and delay localization. The difference between KUBC and PBC is largest for plane-strain tension and shear-dominated loading, while the responses become increasingly similar as the stress triaxiality increases. Increasing the number of voids from 5 to 25 reduces the scatter and narrows the gap between KUBC and PBC, but still the influence of boundary conditions remains significant for all loading cases considered. The study further demonstrates that descriptors accounting for spatial clustering are better predictors of failure strain than porosity or average spacing alone. Highly clustered void distributions promote aligned localization paths, stronger strain localization, and earlier failure, while more uniformly distributed voids tend to delay coalescence. These findings suggest that statistical descriptors of void clustering and spatial heterogeneity should be incorporated in micromechanical and continuum-scale fracture models.