The scatter in ductile fracture: Effect of void distribution

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Abstract

Ductile fracture by void growth to coalescence is one of the major failure modes of metal alloys. Voids nucleate from inclusions and/or second phase particles and then grow by plastic flow under mechanical loading. In most cases, scale separation applies, i.e. the distance between these voids is very small compared to the size of the structure, justifying the development and use of homogenized models for porous materials to simulate ductile fracture (1). However, in some cases, scale separation breaks down due to the miniaturization of the samples/devices or the fabrication process, e.g. additive manufacturing, or both (2). In this regime, the void distribution is important, as shown experimentally and numerically, leading to a scatter of ductile fracture properties such as fracture strain / stress. This scatter has been predicted by performing direct numerical simulations that take into account realistic void distributions (3). However, this approach is computationally intensive, especially when statistical information about the scatter is considered. Therefore, the aim of this study is to develop a model to predict the scatter of ductile fracture properties induced by void distributions. A 2D model is first developed, considering plane strain conditions for an isotropic von Mises material, for random void distributions under uniaxial loading. Limit analysis is used to provide semi-analytical estimates of the plastic dissipation/stress associated with the localization of plasticity between two voids, as a function of intervoid distance and angle. These estimates are validated and calibrated against reference finite element simulations. Graph theory is then used to find the minimum dissipation path, which is considered to be the expected localization path / fracture path. These predictions are again compared with reference finite element simulations. Very good agreement is obtained for the localization stress and localization path. The model is used to predict the scatter of ductile fracture properties as a function of porosity and void number, allowing the effect of void distributions on the mean and standard deviations of fracture stress/strain to be estimated. In particular, the number of voids above which scale separation is restored can be predicted, as well as the optimum void distribution - for a given porosity and void number - that maximizes fracture strain. In addition, the results of this model are compared with the predictions of a generative deep learning model inspired by (4), where the advantages and disadvantages of both approaches are discussed. Finally, extensions to the previous models are detailed, focusing

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on the 3D aspect and the interplay between material anisotropy and void distribution, and comparisons to experimental results are presented.

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