On the role of secondary porosity and associated ‘Size-effects’ in the mechanism of void growth and coalescence

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Abstract

Ductile fracture in metals is an area of active research. While the mechanism of failure (void nucleation, growth and coalescence) in ductile materials is well-understood, the existing models still have several limitations in an accurate prediction of this phenomenon. These models need to be enriched with a more precise understanding that can be obtained from the studies at lower length scales.

In many structural steels, the nucleation and growth of a second population of smaller voids in the ligament between the larger voids accelerates the damage process leading to a severe reduction in ductility. In this work, detailed three-dimensional finite element based cell model studies were performed to understand the role of secondary porosity in the mechanism of void growth and coalescence in porous plastic solids. In contrast to previous studies, the two populations of voids (primary and secondary) were modelled explicitly and the void interactions, across the two length scales, in a realistic 3D state of stress were reported. Numerical studies were carried out to cover a wide range of variation in the initial volume fractions of both primary and secondary voids, relative position of the secondary voids in the ligament between the two primary voids, and applied stress tri-axiality. In addition, the effect of secondary void size on the void growth and coalescence were analysed in detail. It was demonstrated that the smaller size secondary voids (for the same volume fraction) lead to an early onset of plastic flow localisation and, thus, reduces the macroscopic ductility. Moreover, the parameters of the GTN model that have been used in past to analyse the effects of the secondary porosity on void growth and coalescence do not lead to satisfactory results particularly for low and moderate stress tri-axiality.

In particular, the homogenised representation of the secondary voids, employing these parameters, leads to an under-prediction of the total porosity. Such a discrepancy between the results obtained from the GTN model and those obtained from explicit modelling of secondary voids clearly indicates that the parameters of the GTN model that are presently being used to analyse the effects of secondary voids lack a micromechanical basis. Even if these parameters are tuned, based on the results of explicit cell model studies, the ‘size-effects’ associated with the secondary voids, and the effects of secondary void distributions on void growth and coalescence cannot be predicted by such local damage models. The limitations of non-local damage models to analyse the ‘size-effects’ of the secondary voids were also highlighted. It is expected that the new insights gained from the present study will be helpful in the development of improved ductile fracture models.

After completing my graduation in Mechanical Engineering (B. Tech), I joined Bhabha Atomic Research Centre (BARC), India, in September, 2000. I am presently working in BARC as Scientific Officer-F (equivalent to Associate Professor). I have been working in the general area of Fracture mechanics, Plasticity, and Computational Materials Modelling and I have made several original contributions. My research involves theoretical analysis, computational simulations and experimental work. I did my PhD on ‘weld centre cracks’ and the research work was published in leading international journals (05 articles). In addition to being a researcher, I also am serving as a faculty member in BARC Training school and I deliver lectures on ASME code design for pressure vessels and piping, and Finite element method as a part of training program of the newly recruited graduate engineers. I have the experience of working on collaborative research projects and I have worked twice as a Guest Scientist at MPA, University of Stuttgart, Germany under the Indo-German bilateral program on “fracture and fatigue assessment of dissimilar metal weld joints” in 2006, 2007. I have more than 50 publications (mostly as first author) to my credit. I have also supervised many graduate and post-graduate students towards successful completion of their academic projects. I am also serving as the co-coordinator for preparation of question papers for Mechanical discipline for recruitment of graduate engineers in BARC. I am also responsible for the development of an advanced facility for testing of refractory metals and ceramics at high temperature (above 1000°C) in vacuum environment.

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