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Ductile fracture: Experiments and computations

H. Li [a,b], M.W. Fu [a,*], J. Lu [a], H. Yang [b]

[a] Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, PR China
[b] School of Materials Science, State Key Lab of Solidification Processing, Northwestern Polytechnical University, Xi'an, PR China

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ABSTRACT

Numerous criteria have been developed for ductile fracture (DF) prediction in metal plastic deformation. Finding a way to select these DF criteria (DFCs) and identify their applicability and reliability, however, is a non-trivial issue that still needs to be addressed in greater depth. In this study, several criteria under the categories of 'uncoupled damage criterion' and the 'coupled damage criterion', including the continuum damage mechanics (CDM)-based Lemaitre model and the Gurson–Tvergaard–Needleman (GTN) model, are investigated to determine their reliability in ductile failure prediction. To create diverse stress and strain states and fracture modes, different deformation scenarios are generated using tensile and compression tests of Al-alloy 6061 (T6) with different sample geometries and dimensions. The two categories of criteria are coded into finite element (FE) models based on the unconditional stress integration algorithm in the VUMAT/ABAQUS platform. Through physical experiments, computations and three industrial case studies, the entire correlation panorama of the DFCs, deformation modes and DF mechanisms is established and articulated. The experimental and simulation results show the following. (1) The mixed DF mode exists in every deformation of concern in this study, even in the tensile test of the round bar sample with the smallest notch radius. A decrease of stress triaxiality (η-value) leads to a reduction in the accuracy of DF prediction by the two DFC categories of DFCs, due to the interplay between the principal stress dominant fracture and the shear–stress dominant factor. (2) For deformations with a higher η-value, both categories of DFCs predict the fracture location reasonably well. For those with a lower or even negative η-value, the GTN and CDM-based criteria and some of the uncoupled criteria, including the C&L, Ayada and Oyane models, provide relatively better predictions. Only the Tresca and Freudenthal models can properly predict the shear dominant fracture. The reliability sequence of fracture moment prediction is thus the GTN model, followed by the CDM-based model and the uncoupled models. (3) The applicability of the DFCs depends on the use of suitable damage evolution rules (void nucleation/growth/coalescence and shear band) and consideration of several influential factors, including pressure stress, stress triaxiality, the Lode parameter, and the equivalent plastic strain or shear stress. These parameters determine the deformation mode (shear dominant or maximum principal stress dominant deformation) and, further, the DF mechanism (dimple fracture/shear fracture/mixed fracture).

1. Introduction

It is well-known that metal materials may undergo ductile fracture (DF) and the loss of load-carrying capacity, which results from the progressive degradation of material stiffness, when plastic deformation (PD) reaches a certain limit. DF is a

* Corresponding author. Tel.: +86 852 27665527.
E-mail addresses: mmmwfu@polyu.edu.hk, mmmelu@inet.polyu.edu.hk (M.W. Fu).

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