
A micromechanics-based damage model for prediction of sheet metal forming limits

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Abstract

The prediction of failure in sheet metals subjected to complex non-proportional loading paths during forming operations is a challenging, and technologically important, problem. Fracture in sheet metals subjected to biaxial plane stress loading generally occurs following localized necking in the thickness direction. The critical condition for the onset of localized necking depends on the loading path, and constitutive effects such as strain hardening, plastic anisotropy and the formation of vertices on the yield surface. In particular, plastic anisotropy can play a major role in case of sheet metals that develop well defined textures as a result of the rolling operations used in their manufacture. Phenomenological models of sheet metal failure based on the experimentally determined forming limit diagrams (FLD) under proportional loading are known to be inadequate under strongly non-proportional loading paths. Imperfection band approaches such as the widely used Marciniak and Kuczyński (1967) (MK) model are also limited in their predictive ability, since their predictions depend on arbitrary choices of preexisting imperfections in the material. The objective of the present work is to develop a criterion for localized necking in plastically anisotropic sheet metals using a ductile fracture model based on the micromechanics of void growth and coalescence. Classical ductile failure models such as the Gurson (1977) model are unable to predict necking in sheet metals at realistic strain levels due to the assumption of dilute porosities, which lead to prediction of a smooth yield surface and the normality flow rule. However, it is known from several micromechanical simulation studies that the interaction between voids at finite porosities has a significant influence on the effective yield behavior, leading to a transition from diffuse yielding to localized yielding of the inter-void ligaments within a porous representative volume element. The transition from diffuse to an inhomogeneous yielding at the micro-scale results in the formation of macroscopic yield vertices, which can potentially trigger necking instabilities in thin sheets. In the present study, yield criteria for plastically orthotropic materials of the Hill (1948) type, developed by Benzerga and Besson (2001) for diffuse yielding and Keralavarma and Chockalingam (2016) for inhomogeneous yielding, are combined using a multi-surface approach. The shapes of the effective yield surface predicted by the model are validated by comparison with quasi-exact numerical yield loci obtained using a finite elements based limit analysis procedure. A plasticity model based on the above yield criterion, specialized to the plane stress case, is used to predict their forming limits for sheet metals under proportional loading paths, using the plastic instability criterion of Stören and Rice (1975). It is shown that realistic shapes of the FLDs as a function of the plastic anisotropy parameters of the material are predicted using this approach, which does

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not require the assumption of a macro-scale imperfection band as in the MK model.

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