An Anisotropic Plasticity Framework for Damage-Prone Materials with Shear Sensitivity

Jacob Smith*, Jian Cao* and Wing Kam Liu*

* Department of Mechanical Engineering
Northwestern University
2145 Sheridan Rd, Evanston, IL 60208-3111, USA
e-mail: jacobsmith2011@u.northwestern.edu

ABSTRACT

Many engineering materials exhibit strong anisotropic behavior at the onset of plastic flow while also being prone to damage during plastic yielding. While many models have been developed to incorporate plastic anisotropy or damage, there are few models that are general enough to account for both simultaneously while also having a high level of transferability for other materials. The ability to predict the combined effects of the inherent plastic anisotropy and damage of these materials is important for accurately analyzing their behavior during manufacturing processes, e.g., stamping, and also in product-specific applications, e.g., vehicle crash testing. It has also been demonstrated that materials can have a strong sensitivity to shear loading with respect to damage evolution [1]. The present work is directed at three primary goals: (1) developing a general framework for the creation of new damage-prone and shear sensitive material models for various material classes; (2) developing a general anisotropic yield criterion which can be used for general-dimensional stress states and adopts a mechanics-based damage model, the Gurson-Tvergaard-Needleman model with a shear-sensitivity modification [2], such that it can be utilized for a vast number of materials and material classes which are prone to damage during plastic loading; (3) development of a finite element analysis implementation of the yield criterion using the Abaqus user-subroutine for user-defined material models which is used to validate the capabilities of this modeling approach for damage-prone plastically anisotropic materials. It is ideal to have a material modeling approach which can account for general-dimensional stress states, not only because the material itself may have sensitivity to these stress states but also to take advantage of the ability of finite element analysis to simulate near arbitrary complicated geometries in higher dimensions. However, the implementation of a material model in finite element analysis requires that the material model itself be posed in such a way that a corresponding stress update algorithm can be devised which incorporates the correct dimensionality and mechanics, this being another one of the primary motivations of this research. Furthermore, the developed model is based on an extension of a previously developed general anisotropic yield criterion, created by Karafillis and Boyce (1993) [3], in which the so-called isotropic plasticity equivalent stress is augmented with the pressure from the anisotropic stress state in order to account for non-deviatoric mechanics. The motivation behind basing this work on the Karafillis and Boyce model is that this particular model allows for general non-quadratic behavior in the yield criterion as well as plastic anisotropy. This implies that the developed damage-based anisotropic plasticity model will actually be driven by an equivalent stress value that represents a number of different materials depending on the non-quadratic behavior of the yield surface. While in the current research the mechanics-based Gurson-Tvergaard-Needleman model has been selected for incorporating damage, the developed yield criterion can be equivalently extended for any damage-based model.

REFERENCES

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