An elasto-plastic damage constitutive theory and its prediction of evolution of subsequent yield surfaces and elastic constants

Liu Fang *, Fu Qiang, Chen Cen, Liang Naigang
State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China

Abstract
Based on pair functional potentials, Cauchy–Born rule and slip mechanism, a material model assembling with spring-bundle components, a cubage component and slip components is established to describe the elasto-plastic damage constitutive relation under finite deformation. The expansion/shrink, translation and distortion of yield surfaces can be calculated based on the hardening rule and Bauschinger effect defined on the slip component level. Both kinematic and isotropic hardening are included. Numerical simulations and predictions under tension, torsion, and combined tension–torsion proportional/non-proportional loading are performed to obtain the evolution of subsequent yield surfaces and elastic constants and compare with two sets of experimental data in literature, one for a very low work hardening aluminum alloy Al 6061-T6511, and another for a very high work hardening aluminum alloy annealed 1100 Al. The feature of the yield surface in shape change, which presents a sharp front accompanied by a blunt rear under proportional loading, is described by the latent hardening and Bauschinger effect of slip components. Further, the evolution law of subsequent yield surfaces under different proportional loading paths is investigated in terms of their equivalence. The numerical simulations under non-proportional loading conditions for annealed 1100 Al are performed, and the subsequent yield surfaces exhibit mixed cross effect because the kinematic hardening and isotropic hardening follow different evolution tendency when loading path changes. The results of non-proportional loading demonstrate that the present model has the ability to address the issue of complex loading due to the introduction of state variables on slip components. Moreover, as an elasto-plastic damage constitutive model, the present model can also reflect the variation of elastic constants through damage defined on the spring-bundle components.

1. Introduction

Most sheet metal forming processes involve anisotropic behaviors with finite plastic deformation. Springback is a serious problem in sheet metal forming. It requires a comprehensive understanding of loading and unloading processes and determination of elastic constants to know the amount of springback for a given forming process. Therefore, it needs precise determination of subsequent yield surfaces. Researchers are focused on the evolution of yield surfaces either experimentally or analytically.

There are numerous investigations found in determination of yield surfaces for small (<5%) prestrains including the ones by Naghdi et al. (1958), Ivey (1961), Michael and Findley (1976), Phillips and Ricciuti (1976), Moreton et al. (1981), Ascione