How to reduce weight and increase fuel efficiency is a critical challenge in transportation industries. One way to resolve the problem is to adopting lightweight alloys (i.e. advanced high strength steel, aluminum alloys, or magnesium alloy) in structure designs and manufacturing. Fully understanding the mechanical properties of these materials is a key step. In order to fully characterize the plasticity and fracture of magnesium AZ31B-H24 sheets, a set of mechanical experiments (170 in total) were performed under both monotonic and non-proportional loading conditions, including monotonic uniaxial tension, notch tension, in-plane uniaxial compression, wide compression (or called biaxial compression), plane strain compression, through-thickness compression, in-plane shear, punch test, uniaxial compression-tension reverse loading, and two-step uniaxial tension (cross-loading).

Both the plastic strain histories and stress responses were obtained under the above loading conditions, which give a comprehensive picture of mechanical behaviors of this material. No apparent cross-hardening effect was observed for this material. An extended orthotropic yield criterion involving two linear anisotropic transformation tensors, CPB06ex2, in conjunction with its associated flow rule was fully calibrated to describe both the anisotropy in plastic flow and tension-compression asymmetry in stress-strain behaviors.

A fully modularized framework to combine isotropic, kinematic, and cross hardening behaviors was established under non-monotonic loading conditions. Three sets of state variables were defined and applied to consider the effects of, a) loading history, b) twinning and de-twinning and c) different pre-strain.

In order to predict ductile fracture of metal sheets, the mixed stress/strain invariants based Modified-Mohr-Coulomb (MMC) fracture model was transferred into an all-strain based MMC (eMMC) model under plane stress condition, predicting the fracture strain dependent on strain ratio or \( \Phi \) angle, instead of stress triaxiality and Lode angle parameter. The strain ratio or \( \Phi \) angle could be directly measured by digital image correlation (DIC), while the latter required finite element analysis to be determined. This method makes it possible to study material fracture behavior while bypassing plasticity. The eMMC fracture locus can be fully calibrated by fracture strains directly measured from DIC. The fracture strain was also extended by a linear transformation operating to the plastic strain tensor to incorporate the fracture anisotropy. All models were implemented into Abaqus/Explicit as a user material subroutine (VUMAT). Good prediction capability has been demonstrated for magnesium AZ31B-H24 sheets by FE simulation using shell elements.

The current framework was also applied for TRIP780, BH240, DP600, and EDDQ steel sheets with adjustment, under different loading conditions. The FE simulation results for TRIP780 correlated well with experimental data under different monotonic loading conditions. The analytical results for BH240, DP600, and EDDQ demonstrated good prediction capability for cross-hardening behavior, and validated by the non-proportional experimental data under two-stage uniaxial tension.
Approved for distribution by Yuanli Bai, Committee Chair, on February 15, 2016.

The public is welcome to attend.