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A New Coupled Thermomechanical Framework for Modeling Formability in Transformation Induced Plasticity Steels

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Abstract

Transformation induced plasticity (TRIP) steels have significant volume fractions of retained austenite that can undergo a strain induced transformation into martensite. This transformation, known as the TRIP effect, produces a high hardening capacity that can lead to enhanced formability, which can result in weight reduction and improved vehicle fuel efficiency for automakers. In this paper, a phenomenological framework for TRIP steel is integrated into a Marciniak-Kuczynski (MK) model coupled with a thermal solver to create a new fully coupled thermomechanical formulation to evaluate formability. The constitutive model was calibrated to capture the kinematics of martensite and flow stress dependence on strain rate, temperature, triaxiality, and stress asymmetry for TRIP 800 steel. Several sensitivity and exploratory studies are performed to highlight critical mechanisms for modeling TRIP in formability. Kinematic effects of transformation are shown to have a minor effect on formability compared to the hardening and evolving yield surface effects. Thermal effects, such as conduction, convection, and radiation heat transfer, are shown to be crucial for the formability of TRIP 800 at elevated sheet temperatures with room temperature external boundaries, but not for elevated external boundaries. By modifying the sheet initial thermal conditions, martensite transformation could be controlled to be able to delay localization and enhance formability in the plane strain and uniaxial formability by 25% and 35% respectively.

Keywords: **Phase Transformation; Thermomechanical Modeling; Forming Limit Diagram; MK Analysis; TRIP steel**

1 Introduction

Automakers have been focusing on structural light weighting as a strategy to meet government regulations in vehicle fuel efficiency (USEPA, 2016). In conjunction with new design technologies (Kohar et al., 2015; Kohar et al., 2016a), new advances in materials and manufacturing processing are allowing automakers to replace low carbon steel components with lightweight aluminum (Kohar et al., 2017), magnesium (Pollock, 2010; Rossiter et al., 2012), composites (Zhang et al., 2012, Friedrich and Almajid, 2013), and advanced high strength steels (AHSS) (Link and Grimm, 2005a, 2005b; Omer et al., 2017). The incorporation of AHSS into the vehicle structural is attractive for manufacturers as it takes advantage of currently available stamping and forming technologies.

Within the family of AHSS, the transformation induced plasticity (TRIP) effect is a hardening and deformation mechanism that results from the transformation of retained metastable austenite (γ)

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