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The shear fracture of dual-phase steel

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ABSTRACT

Unexpected fractures at high-curvature die radii in sheet forming operations limit the adoption of advanced high strength steels (AHSS) that otherwise offer remarkable combinations of high strength and tensile ductility. Identified as “shear fractures” or “shear failures,” these often show little sign of through-thickness localization and are not predicted by standard industrial simulations and forming limit diagrams. To understand the origins of shear failure and improve its prediction, a new displacement-controlled draw-bending test was developed, carried out, and simulated using a coupled thermo-mechanical finite element model. The model incorporates 3D solid elements and a novel constitutive law taking into account the effects of strain, strain rate, and temperature on flow stress. The simulation results were compared with companion draw-bend tests for three grades of dual-phase (DP) steel over a range of process conditions. Shear failures were accurately predicted without resorting to damage mechanics, but less satisfactorily for DP 980 steel. Deformation-induced heating has a dominant effect on the occurrence of shear failure in these alloys because of the large energy dissipated and the sensitivity of strain hardening to temperature increases of the order of 75 °C. Isothermal simulations greatly overestimated the formability and the critical bending ratio for shear failures, thus accounting for the dominant effect leading to the inability of current industrial methods to predict forming performance accurately. Use of shell elements (similar to industrial practice) contributes to the prediction error, and fracture (as opposed to strain localization) contributes for higher-strength alloys, particularly for transverse direction tests. The results illustrate the pitfall of using low-rate, isothermal, small-curvature forming limit measurements and simulations to predict the failure of high-rate, quasi-adiabatic, large-curvature industrial forming operations of AHSS.

1. Introduction

From the start of mass production until approximately twenty years ago, establishing a sheet forming operation for a new part shape required multiple stages of experimental die tryout, often over a period of many months or years. This process changed radically with the advent of faster computers and nonlinear finite element methods, which allowed sufficiently accurate prediction of forming strains. These strains were then compared with forming limit diagrams to detect problem configurations and suggest die improvements, all before any dies were made. Today, virtually all automotive sheet-formed

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