Fracture Analysis of AHSS During Draw-Bending

Executive Summary

A/S/P Auto/Steel Partnership

Final Report

Fracture Analysis of Advanced High Strength Steels during Draw-Bending

Experiments, Simulations, and Failure Models

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EXECUTIVE SUMMARY

Advanced high strength steels (AHSS) have been increasingly used for car body structures by the automotive industry for better crash worthiness and fuel economy. However, manufacturing automotive structural components with AHSS poses new forming challenges. One of these challenges is "shear fracture" that more often occurs when AHSS material is drawn and bent at the radius of forming tools. Shear fracture and the inability to predict it during stamping has been the major barrier limiting the use of AHSS in the automotive industry. Therefore, it is desirable to develop practical and reliable criteria to predict shear fracture of stamping AHSS in finite-element analysis (FEA).

In this study, the following three failure models were developed or determined.

- The Hollomon/Voce (H/V) material constitutive model
- The Normalized Cockcroft & Latham (NCL) damage model
- The Gurson-Tvergaard-Needleman (GTN) damage model

These failure criteria were established using the various formability tests (e.g., tensile, biaxial, and draw-bend tests) and evaluated with different commercial finite-element (FE) modeling codes (e.g., ABAQUS, DEFORM, and LS-DYNA) by simulating the formability tests (e.g., tensile and draw-bend tests) and a B-pillar stamping.

The following major conclusions were drawn from this study:

- From examination of AHSS stamped parts, shear fractures were more often found in (i) a sharp bending radius, (ii) stretch-bending at draw-beads, and (iii) plane-stain bending areas. Scanning electron microscope (SEM) analyses of shear fractured sections of a B-pillar part and a draw-bend sample showed similar ductile dimple rupture and a number of micro-voids.

- To quantify the micro-void formations as the plastic strain increased, the stop-tensile tests were conducted for DP590(B), DP780(D), TRIP780(D), DP980(D), and DP980(A). Stop-tensile tests showed the growth and coalescence of micro-voids as the plastic stain increased from ultimate tensile strength (UTS) to fracture point. The results (e.g., the average size of void and the area fraction of voids) were input for determining the GTN damage model (i.e., micro-void-based model).

- A new draw-bend formability test using velocity control of two actuators successfully mimics the mechanics of deformation of sheet metal as it is drawn, stretched, bent, and straightened over a die radius entering a typical die cavity.

- Three kinds of fracture occur for the velocity control draw-bend fracture (DBF) test with AHSS depending on material, radius-to-thickness ratio (R/t ratio), draw speed (V_1), and draw speed ratio (V_2/V_1): Type I is a standard tensile fracture, Type III is a "shear fracture" that occurs in a bending region as material is drawn over a die radius, and Type II is a mixed fracture that initiates in a hardened region that has been drawn over the tool and near the tool radius but propagates more like a tensile fracture, usually into an undeformed region of the strip.

- $(R/t)^*_1$, the critical value of bending ratio between two fracture types, is one measure of formability of AHSS. Based on $(R/t)^*_1$, the formability order for testing in the RD (RD) is TRIP780(D) ≈ DP590(B) > DP780(D) > DP980(D) > DP980(A) > DP980(E) > DP980(F). In addition, failure maps of tested materials were generated based on $(R/t)^*_1$.

- The front displacement to failure (U_f) was defined as an alternative and more sensitive measurement of formability. The formability order based on U_f is DP590(B) > TRIP780(D) > DP780(D) > DP980(D) > DP980(A) > DP980(E) > DP980(F) for the RD of each material. Failure plots based on U_f were generated.

- Thermally-assisted strain localization has a major effect on the type of fracture, when it occurs, and on the discrepancy between low-rate, isothermal forming limit diagram (FLD) measurements and industrial practice. With this new constitutive model, no damage model is additionally required to understand and predict the fracture of DP590(B), DP780(D), and DP980(D) for RD tests, but for one material tested, the RD results can show significantly lower formability for similar constitutive behavior, an effect attributed to directional micro-structural properties rather than constitutive ones.

- The GTN damage model with the H/V flow stress model for DP980 (D) was applied to the non-isothermal FE simulation for the partial B-pillar model. The final temperature and the severities of micro-void coalescence of critical area of formed part were predicted by DEFORM. However, for the industry usage of this morel, more development works are required in future.

- In a full-scale B-pillar stamping simulation with LS-DYNA, the maximum thinning values predicted by both adiabatic model and the Holloman model showed very small differences (e.g., 0.6% for DP780D and 0.7% for DP980D). Both models predicted the maximum thinning areas to be close to the actual shear fracture locations of B-pillar part. However, it was difficult to ensure that the predicted maximum thinning areas to be actually failed by considering only thinning

comparison and without FLD comparisons, because the maximum thinning values predicted by both models were between the uniform elongation and the total elongation.

- The damage plot was made in the post processing of LS-DYNA result by using the NCL damage model. The maximum damaged areas were predicted to be multiple locations that include the actual shear fracture locations. The numerical implementation (e.g., damage-induced material softening and/or element eliminations) of the NCL model in LS-DYNA can be the future development work for the software company.

- In this project three unique criteria (e.g., a new material constitutive model and two damage-based fracture models) were introduced for the industry usage of predicting shear fracture in stamping AHSS with FEM. Detailed procedures were developed in this study to allow the prediction of forming fractures of AHSS using commercial FEM codes. By adopting one of these failure criteria and possibly compensated FLD's, simulations of forming operations are expected to predict shear fractures of AHSS more accurately.