

Development of Empirical Shear Fracture Criterion for AHSS

2010-01-0977

Published
04/12/2010

Hua-Chu Shih and Ming F. Shi
United States Steel Corporation

Danielle Zeng and Z. Cedric Xia
Ford Motor Company

Copyright © 2010 SAE International

ABSTRACT

The conventional forming limit curve (FLC) has been widely and successfully used as a failure criterion to detect localized necking in stamping. However, in stamping advanced high strength steels (AHSS), under certain circumstances such as stretching-bending over a small die radius, the sheet metal fails much earlier than predicted by the FLC. This type of failure on the die radius is commonly called “shear fracture.”

In this paper, the laboratory Stretch-Forming Simulator (SFS) and the Bending under Tension (BUT) tester are used to study shear fracture occurring during both early and later stages of stamping. Results demonstrate that the occurrence of shear fracture depends on the combination of the radius-to-thickness (R/T) ratio and the tension/stretch level applied to the sheet during stretching or drawing. Based on numerous experimental results, an empirical shear fracture limit curve or criterion is obtained. It is observed that all data points above this shear fracture limit curve show shear fracture while data points below this line show tensile failure (localized necking) regardless of the test methods used. The empirical shear fracture limit curve for several AHSS is obtained. This failure criterion can be used in computer simulations to predict the shear fracture phenomenon in the entire deformation process involved in a sheet metal stretching or drawing over a die radius.

INTRODUCTION

Conventional automotive mild and high strength steels are being replaced by advanced high strength steels (AHSS) due to the demands for vehicle weight reduction and safety performance improvement. However, one of the

manufacturing issues to be addressed for AHSS is shear fracture during stamping. Shear fracture usually happens on the radii of part geometries at strains below the conventional forming limit of the material and thus computer simulations often fail to predict this type of fracture using the conventional forming limit as the failure criterion. In a previous study on springback control of AHSS, this type of shear fracture was observed by Shih [1] using the bending under tension test. Various combinations of the critical back tension stress versus the radius to thickness (R/T) ratio were identified where the failure occurred on the radius. Later, Walp et al. [2] and Hudgins et al. [3] conducted a series of shear fracture tests using the modified Duncan Shabel tester, angular stretch bend tester and bending under tension tester. Both studies suggested that a single critical R/T for each test material exist for shear fracture in stretch bending for AHSS. In other words, any part designed with an R/T ratio smaller than this critical R/T value would have shear fracture failure and shear fracture would not occur if the R/T ratio is greater than the critical value. Shih et al. [4] conducted experimental studies on shear fracture of AHSS using the modified Stretch Forming Simulator (SFS) and found that shear fracture depends not only on the R/T ratio but also on the tension applied during stretch bending. Shear fracture may not occur at a small R/T ratio if the tension level during bending is not high enough. This finding was also verified using the finite element analysis (FEA) by Zeng et al. [5]. Shih et al. [6] later further verified this finding using the Bending Under Tension (BUT) test for a DP780 AHSS. Furthermore, a shear fracture limit curve was discovered when the data from the SFS were compared to those from the BUT. In this study, experimental work is conducted for several other AHSS including DP600, DP780, TRIP780 and DP980 using the BUT tests. It is confirmed that a shear fracture limit curve exists for all

AHSS and this limit curve can be used to detect the shear fracture limit based on the R/T ratio and tension level applied during bending. It is also found that the shear fracture limit curve is higher when the bending axis is perpendicular to the rolling direction of the sheet than when the bending axis is parallel to the rolling direction of the sheet. This difference becomes more significant for higher grades of AHSS.

MATERIALS

Five different materials, including four different AHSS and a HSLA340 were selected in this study. The mechanical properties of the tested materials are listed in the [Table 1](#).

<[table 1](#) here>

Table 1. Mechanical properties of tested steels

Material	Thickness (mm)	Rolling	Yield Strength (MPa)	Tensile Strength (MPa)	Total Elong. (%)	N Value
HSLA340	1.4	L	422	491	26.7	0.15
HSLA340	1.4	T	436	494	23.6	0.14
DP600	1	L	395	654	25.8	0.15
DP600	1	T	413	660	21.4	0.15
DP780	1	L	511	869	17.3	0.13
DP780	1	T	517	894	15.4	0.12
TRIP780	1	L	454	798	18.8	0.14
TRIP780	1	T	493	820	17.1	0.15
DP980	1	L	674	1080	13.4	0.11
DP980	1	T	675	1091	12.6	0.113

The n-value was measured from the strain range between 10% and the end of the uniform elongation except for DP980, in which the strain range between 7% and uniform elongation is used.

PROPOSED SHEAR FRACTURE LIMIT CURVE

As described in [6], the bending under tension test shown in [Figure 1](#) can be used for the shear fracture test and shear fracture can be re-produced for AHSS at a given R/T ratio when a sufficiently high back tension is used. It has been demonstrated in [6] that, for a given R/T value, different failure locations and/or failure types can be generated using various restraining forces or back tensions during the test. At a low restraining force, the sample is able to be pulled over the radius without failure at the maximum pulling distance while, at a high restraining force, the sample would fail in the radius contact areas, which is commonly referred to as shear fracture.

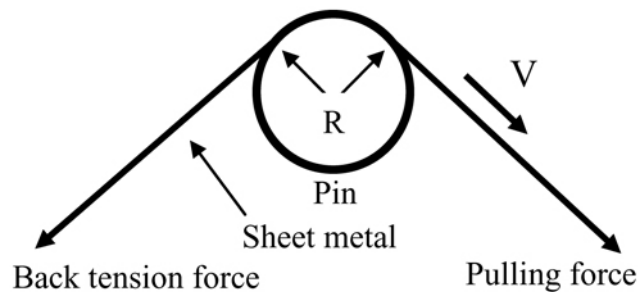


Figure 1. Schematic drawing of BUT test

In the BUT test, the dimension of the test specimen is 25.4 mm × 635 mm with 635 mm along the transverse direction of the sheet (transverse specimen) and thus the bending axis during test is along the rolling direction. The burrs from shearing were removed before the test using a fine file to prevent edge cracking during testing and a thin Teflon® fluoropolymer film was used as the lubricant during the test.

[Figure 2](#) shows the engineering stress vs. the R/T ratio data for 1.0 mm DP780 obtained from the BUT test. The engineering stress is calculated from the maximum pulling force divided by the original cross-section areas of the specimen and can be treated as the average tension stress applied during bending; R is the die radius and T is the original specimen thickness. For a given R/T value, several samples were tested using various restraining forces. The data points with a shaded square symbol represent the tests with no fracture on the specimen after the test, which corresponds to tests with a low restraining force, as shown in [Figure 3](#) with the photos of tested specimens. The data points with a triangle symbol correspond to those specimens failing in the side wall (tensile failure) while the data points with a “x” symbol are for those specimens that fail in the radius contact area (shear fracture). It is observed that there are data points (hollow square symbol) followed between the tensile failure in the side wall and shear fracture in the radius contact areas. Those data points typically represent the failure between the side wall and the radius contact area or the tangent point and are hard to determine the precise fracture locations of inside radius or outside radius.

As shown in [Figure 2](#), however, those data points always follow between the failed inside the radius and the side wall for a given R/T ratio. Therefore, this tangent point can be used as the shear fracture limit point for a given R/T ratio, where any points above this point are treated as shear fracture and any points below this point as tensile failure. When two or more tangent failure points are obtained, as shown in the case with the R/T ratio at 1.5 in [Figure 2](#), the lowest point should be selected as the tangent point. By connecting all tangent failure points at various R/T ratios, the obtained curve can be used as the shear fracture limit curve for the given material, as shown in the dash line in [Figure 2](#) for 1.0 DP780