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Examining edge cracking in hole flanging of AHSS

The automotive industry increasingly uses advanced high-strength steels (AHSS) to satisfy requirements for crash resistance and fuel efficiency. Stamping of AHSS poses several challenges, one of which is edge cracking. In stamping automotive parts, the excessive material in a drawn part is trimmed off to make the final part. During flanging and hemming or even in the initial forming process, the drawn and trimmed parts experience tensile strain and stress that occur at the trimmed edges, resulting in edge cracking (see **Figure 1**).

Factors such as edge condition before flanging, punch shape, shearing operation, and the microstructure (volume fractions of the different phases) affect the ability of the hole flange to stretch. The forming limit curve (FLC) traditionally used to evaluate formability is not sufficient to predict potential edge cracking because FLC represents the limit of stretching but not bending.

Therefore, the edge stretchability is studied using a hole expansion test that can emulate the stress/strain conditions formed during hole flanging. In the hole expansion test, a pierced hole is expanded to fracture using a conical, hemispherical, or flat-bottom punch to evaluate its edge stretchability. A blank holder clamps the sheet to restrict the material movement in the flange (see **Figure 2**). The edge of the hole is under stretching and bending conditions. Therefore, the circumferential strain/stress along the edge leads to cracking. It is most probable, however, that a complex stress/strain history, and the edge quality of the pierced hole, can determine when edge cracking occurs.

A hole expansion ratio is used as a criterion to evaluate the hole flange stretchability:

$$\lambda = \frac{d_f - d_o}{d_o} \times 100$$

where d_f and d_0 are final and prehole diameters, respectively. The higher the hole expansion ratio (λ), the better the stretchability of the hole flange.

Researchers investigated the edge stretching limits of various steel grades with different sheet thicknesses using hole flanging experiments with both a conical punch and a flat- bottom punch to punch the material.[1] The researchers observed that mild steel and high-strength steel (HSS) had hole expansion ratios beyond 100 percent while the AHSS [transformation-induced plasticity (TRIP), dual-phase (DP), recovery annealed steel (RA), and martensitic steels] have expansion ratios of about 50 percent (see **Figure 3**). Also, TRIP steels have the same hole expansion ratio as DP steels, although TRIP steels generally have better formability than DP steels,

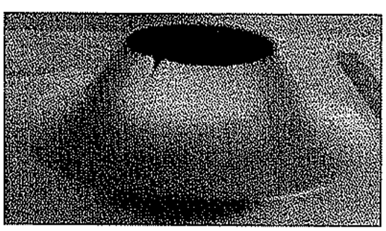

Figure 1

In this example of edge cracking in hole flanging, a round hole pierced in a sheet was expanded using a cylindrical punch. Photo courtesy of S. Sadagopan et al., 2003.

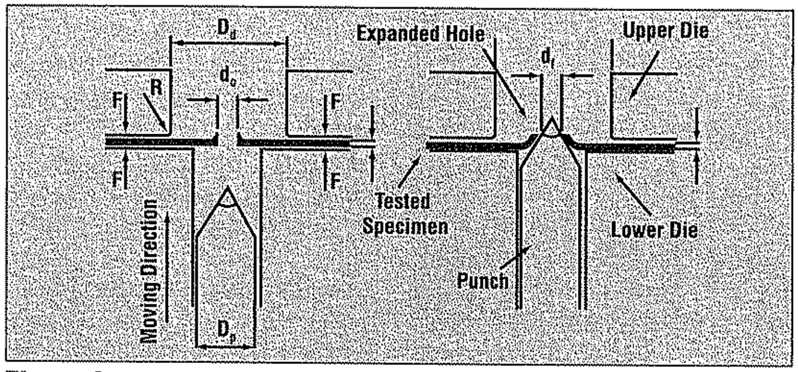

Figure 2

A schematic of a hole expansion test with a conical punch is used to evaluate how far a sheet sample can be flanged without fracture. Diagram courtesy of A. Karelova et al., 2007.

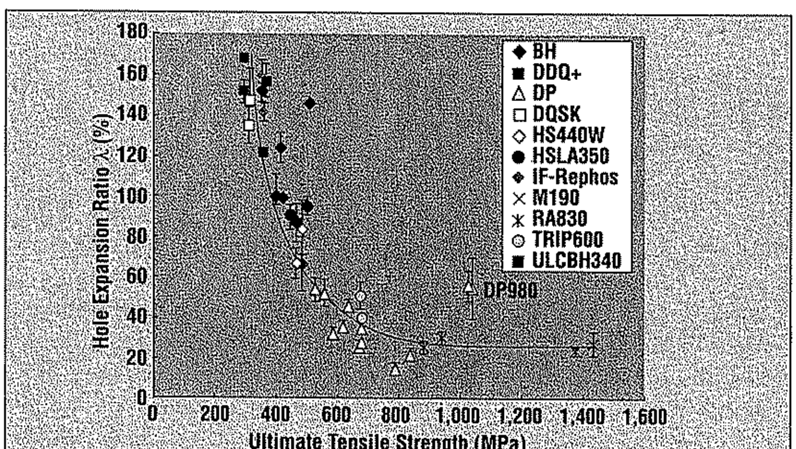

Figure 3

Hole expansion ratios (λ) of mild steel and AHSS in a hole expansion test using a conical punch are compared. Chart courtesy of Sadagopan et al., 2003.

as measured by total elongation in the tensile test.

Effects of Edge Quality, Microstructure

Various shearing operations that are used to form the prehole, as well as the tool's condition, directly influence sheared edge quality. Tests showed that, as expected, the hole expansion ratio of AHSS decreased as the punch wore out during production.[2]

Other studies showed that hole flange stretchability of a wire-cut hole was better than a drilled or punched hole, indicating that the edge quality of the hole has a significant influence upon hole flange stretchability. Also, the level of martensite in the material and the homogeneity of its microstructure had considerable influence on hole flange stretchability.[3] For example, CP 800 has more homogenous microstructure compared to DP 800. Therefore, although CP 800 has lower formability in terms of tensile properties, hole expansion ratios are lower for DP 800.

Prediction of Edge Cracking in Hole Flanging

It is desirable to predict and eliminate the edge cracking in hole flanging. Some studies use FEA together with thickness distribution and damage value as a fracture criterion.

In our preliminary study, the FEA commercial code DEFORM-2D was used to establish a relationship between the stress/strain states in hole flanging, material properties, and the edge quality of the prehole. We compared the FEA predictions for mild steel and HSS with experimental data from other research (see **Figure** 4).[4] The initial blank had an outer diameter of 80 millimeters and a prehole diameter of 10 mm. The die and punch diameters were 42.5 mm and 40 mm, respectively. A conical punch with an angle of 60 degrees was used.

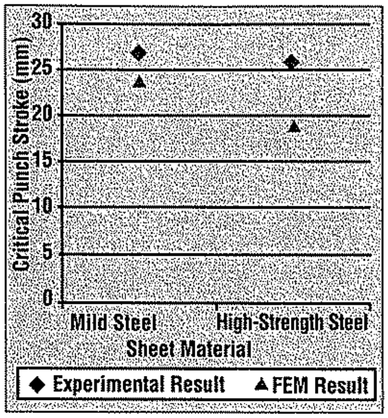

Figure 4

FE and experimental results were obtained by Takuda et al., 1999, for hole flanging with a conical punch. The critical punch stroke is the punch position where edge cracking occurs.

Preliminary FEA simulation results showed agreement with experimental data. Similar results were obtained when comparing the FE predictions with hole flanging using a spherical punch.

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Notes

1. *S. Sadagopan, D. Urban,* Formability Characterization of New Generation of High Strength Steels *(AISI/DOE road program, www.autosteel.org), 2003.*

2. *B. Carlsson, P. Bustard, D. Eriksson,* Formability of High Strength Steel Dual Phase Steels, *Paper F2004F454, (Borlange, Sweden, SSAB, Tunnplat AB), 2004.*

3. *A. Karelova, C. Krempaszky, E. Werner, T. Hebesberger, A. Pichler,* Influence of the Edge Conditions on the Hole Expansion Property of Dual-Phase and Complex-Phase Steels *(Detroit, Mich.: Material Science and Technology), 2007.*

4. *H. Takuda, K. Mori, H. Fujimoto, N. Hatta, N., "Prediction of Forming Limit in Bore-Expanding of Sheet Metals Using Fracture Criterion,"* Journal of Materials Processing Technology, *Vol. 92-93 (1999), p. 433.*