Edge Fracture in Hole Extrusion and Flanging—Part I Process Variables

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Editor’s Note: This is Part I of a two-part series that discusses the process variables that affect the quality of the blanked edge. Part II, which will appear in the September/October 2018 issue, will discuss how to reduce edge fracture in hole extrusion or collar forming.

Hole extrusion or collar forming is widely used in stamping, as seen in the example part shown in Figure 1. Details of the process are seen schematically in Figure 2. In this process, the blanked hole, with a small diameter \(d\) is extruded to a collar with a larger diameter \(D\). The characteristics of the blanked edge, the ratio between \(D\) and \(d\) and the radius \(R_d\) of the die affect the height \(H\) of the collar that can be extruded. During extrusion, the metal thins due to stretching, thus causing the flange thickness to vary. The thinnest position of the extrusion is at the top edge of the flange. When a higher flange is desired, then extrusion may be utilized. In this case the thickness in the flange is reduced and determined by the punch/die clearance during collar extrusion. However, in extrusion the required flanging or extrusion force is also increased.

Figure 1: (A) Surface crack on the radius (plain strain bending) (B) Edge cracking after hole flanging (C) Shearing crack at the deep drawn edge (D) Edge cracking at flange (E) Edge cracking at open head [Beier et al. (2015)].
Hole extruded features or formed collars are often used to provide mechanical attachments or threads necessary for assembly. Edge fracture in hole extrusion is a major issue in forming and flanging of Advanced High Strength Steels (AHSS) that exhibit considerable strain hardening and low ductility.

Figure 2: Details of the hole extrusion (collar forming) process. \( R_d \): die corner radius, \( T \): sheet thickness before extrusion, \( T' \): sheet thickness after extrusion, \( D \): extrusion or collar diameter, \( d \): initial hole diameter and \( H \): extrusion or collar height [Modified from Boljanovic (2004)].

Considerable amount of R&D is conducted in edge fracture that occurs in hole extrusion, thus research indicates that a large number of variables affect a) the quality of the blanked edge and b) the height of extrusion that can be achieved without fracture. Two articles on this subject were published in November/December 2017 and January/February 2018 issues of the Stamping Journal.

The quality of the blanked edge is affected by 1) material properties (strain hardening behavior, microstructure, presence of inclusions etc.), 2) material thickness, 3) punch/die clearance and its uniformity around periphery of the blanked part and 4) wear of the tools. The height of the collar that can be extruded depends, in addition to the quality of the blanked edge, also by the tool geometry, used in extrusion, i.e. die diameter \( (D) \), die corner radius \( (R_d) \), as well as the punch geometry, as illustrated in Figure 2.
Often the objective is to estimate the diameter \((d)\) of the initial blanked hole, provided we know for the given blank a) the material, b) the thickness \((T)\), the extruded collar diameter \((D)\), the die corner radius \((R_d)\) and the desired extruded collar height \((H)\).

In using relatively low carbon steels, for example AISI 1008 or AISI 1010, the blanked hole diameter can be estimated, by the experience-based formula \(d = D - (2H - 0.86R_d - 1.43T)\) [Boljanovic et al., 2014]. However, for AHSS, such as DP600 or DP780, this formula does not give reliable results and a new method for estimating the diameter \((d)\) must be developed.

**Effect of punch/die clearance in blanking**

It is well-known that the quality of the blanked or sheared edge affects edge cracking when tensile stresses and strains are imposed on the edge during hole extrusion. As seen in Figure 3, the blanked edge is divided into five zones:

1. The roll over zone, where the edge of the sheet is bent by elastic and plastic deformation. The geometry of the roll over zone is determined by the punch/die clearance.
2. The shear or burnish zone, a smooth and shiny area oriented by shearing
3. The main fracture zone, where fracture causes the material to separate
4. The burr that results from fracture
5. The depth of crack penetration that is often equal to punch/die clearance

![Figure 3: Different zones of deformation in a blanked/pierced edge (left), schematic of blanking and the punch/die clearance \((c)\) (right).]
The load-stroke curve of blanking is schematically illustrated in Figure 4. It is seen that when the punch contacts the sheet, the blanking force starts to increase suddenly, while the tool and the press are elastically deformed and stretched. When the fracture zone is reached, the blanking force (with elastic and plastic components) sinks abruptly. The rapid increase of the punch force at the start of blanking and the sudden drop in the force, when the sheet fractures may cause vibrations and excessive loading of the press and tooling, often called reverse loading, at the end of the process. These sudden increase and drop of the blanking force may cause excessive vibrations that may damage the press and tooling, in repetitive operations, especially in blanking AHSS or thick (8 to 10mm) blanks.

![Figure 4: Typical load vs stroke curve in a blanking/piercing process, in most practical operations the reverse load (tonnage) should not exceed 10% of the maximum nominal press capacity.](image)

A recent study in blanking was conducted to investigate the effect of blanking speed upon the edge quality, and the effect of multiple stepblanking using several punch motions, during one blanking stroke. For this study, a 300-ton Aida servo press and a blanking tool provided by KTH, were used to blank TRIP780 sheets [Stemler et al., 2017]. The schematic of the tool used is seen in Figure 5. One of the most interesting results of this study was that the punch/die clearance of the blanking tool (Figure 6) did not seem to be uniform around the circumference of the tool. The rolling direction in the blanked samples was well indicated, as seen in Figure 6. To determine the quality of the blanked edge and to estimate the punch/die clearance at various locations of the
blanked hole, micrographs of the edges were obtained and compared with Finite Element simulations, as shown in Figure 7, for positions 1 and 3. The hole flanging tests indicated that more fractures occurred near the point 1 (Figure 6). This observation can be explained by the difference in the punch/die clearance between the points 1 and 3.

Figure 5: Schematic of tooling provided by KTH and used in blanking studies in a 300-ton AIDA servo press.

Figure 6: Locations of Crack initiation in Hole Flanging – The underlined numbers represent the positions in blanking while the numbers show how many times the crack initiated at that location during hole flanging, when running Hole Expansion Tests.
Figure 7: Comparison of simulations and micrographs of blanked edges (TRIP780 / 1.36 mm)

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References