JMEPEG (2008) 17:316–325
DOI: 10.1007/s11665-008-9220-x

Quality of Trimming and its Effect on Stretch Flanging of Automotive Panels

Sergey F. Golovashchenko

(Submitted October 26, 2007; in revised form January 26, 2008)

Traditional trimming requires accurate alignment of the die shearing edges, typically 5–10% of the blank thickness. Increasing the clearance above the recommended value often leads to generation of burrs on the trimmed surface. These burrs may create difficulties for flanging and hemming operations. Details of trimming technology for panels made out of aluminum sheet AA6111-T4 with elastic offal support will be discussed, including such factors as die radii of the tooling, effect of tooling wear, and trimming angle on the quality of trimmed surface. Also, imperfections on the trimmed edge of the panel may result in reduced formability in stretched flanging and hemming operations. Experimental results quantifying the behavior of trimmed surface in stretching will be provided for both a conventional trimming process and a newly developed process.

Keywords aluminum, automotive, stamping

1. Introduction

Modern product design and manufacturing often utilizes a wide variety of materials. Where once low carbon steel dominated, a variety of materials such as aluminum alloys and advanced high-strength steels are now being utilized. These materials often are capable of reducing weight, increasing strength, and improving product efficiency, which are very important attributes of contemporary automobiles. Although such alternative materials may provide a variety of benefits in product efficiency, these same materials may present difficulties when subjected to manufacturing processes originally designed for low carbon steel.

The process of stamping parts from sheet metal frequently includes blanking, piercing, and trimming operations. The overall quality of the part is often defined by the height of burrs on a sheared surface in addition to dimensional accuracy and the absence of splitting. Burrs are known to decrease the quality and accuracy of stamped parts and are also the sources of potential splits in following operations if stretching is applied along the trimmed surface. Current standards attempt to limit the production of burrs through accurate alignment of the upper and lower edges for shearing operations like trimming, blanking, piercing, etc. According to Ref 1, accurate alignment of the upper and lower shearing edges is required to obtain acceptable surface quality. This alignment is defined as the gap between the shearing edges and must be less than 4.5-6% (Ref 1) of the material thickness (Fig. 1). In most cases, the industrially accepted practice is a gap of 10% of sheet thickness. For common automotive exterior sheet, this translates to a gap of less than 0.06 mm. Other approaches have limited the gap to even smaller percentages of material thickness and thereby further decreased the gap. Unfortunately, the tolerances required by such standards often exceed the capabilities of many trim dies and can still result in the production of trimming imperfections. In order to satisfy the existing standards of quality and to meet customer satisfaction requirements, stamped parts frequently need an additional deburring operation (Ref 2), which is often accomplished as a metal-finish operation and conducted manually. Therefore, deburring adds significantly to the cost of a stamped part.

Another defect known to arise directly from the trimming process is the generation of slivers (Fig. 2). It is highly undesirable since slivers may get attached to the blank surface and distributed to the dies following the trimming operation. The accumulation of slivers on both the die and blank surfaces can result in an unacceptable surface finish when the blank is subjected to press operations: the slivers located on either the dies or the blanks can be forced into the blank surface, as shown in Fig. 3. Generation of slivers, in addition to higher cost compared to steel, is one of the main obstacles preventing wide use of aluminum in auto body panels. Known systems for dealing with such slivers commonly focus on the removal of the slivers from the dies and blanks rather than prevention of sliver generation. Such measures as periodical air blowing or manually cleaning slivers from the die surface are common. The removal of slivers from the dies and the blanks can be time-consuming and expensive. Often the cleaning of dies requires the interruption of automated stamping processes, which is highly undesirable. Furthermore, close visual inspection of a part surface finish is often required and additional metal work may be required to repair indentations caused by the slivers. These processes add to the cost and time of product manufacturing and may lead to an increase in the number of parts scrapped if repair is not feasible.

This article was presented at Materials Science & Technology 2007, Automotive and Ground Vehicles symposium held September 16-20, 2007, in Detroit, MI.

Sergey F. Golovashchenko, Manufacturing & Processes Department, Ford Research & Advanced Engineering, Research & Innovation Center, 2101 Village Rd., Dearborn, MI 48124. Contact e-mail: sgolovas@ford.com.

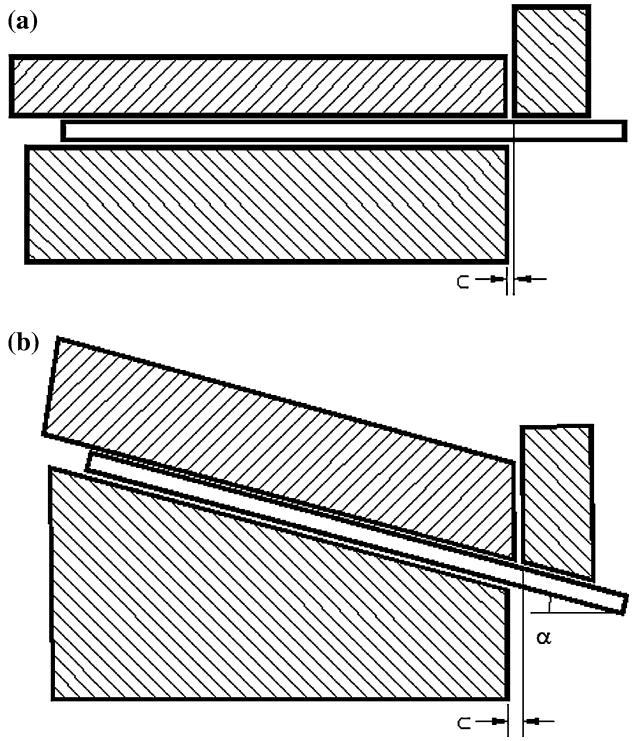

Fig. 1 Conventional trimming process: (a) with no cutting angle and (b) with cutting angle α

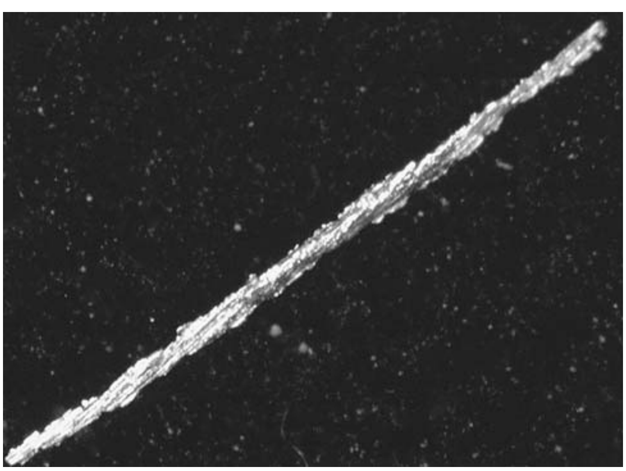

Fig. 2 Typical sliver produced during trimming of aluminum panels

In Ref 3, Li and Fata paid specific attention to the problem of generation of slivers in trimming of aluminum panels. Based on experimental analysis, the authors suggested to use inclined trimming instead of perpendicular trimming. In recent publications by Li (Ref 4, 5), more detailed explanation was provided. According to the shown microstructures and graphs of burr height as a function of the cutting angle, clearance between the shearing edges and the radius of the moving shearing edge, optimal trimming conditions were suggested to occur using a cutting angle of about 15-25° and a dull upper shearing edge. However, in stamping practice usually all sides of the part require a trimming operation, and the cutting angle is often dictated by the geometry of the part; therefore, arranging a specific cutting angle from all sides is problematic.

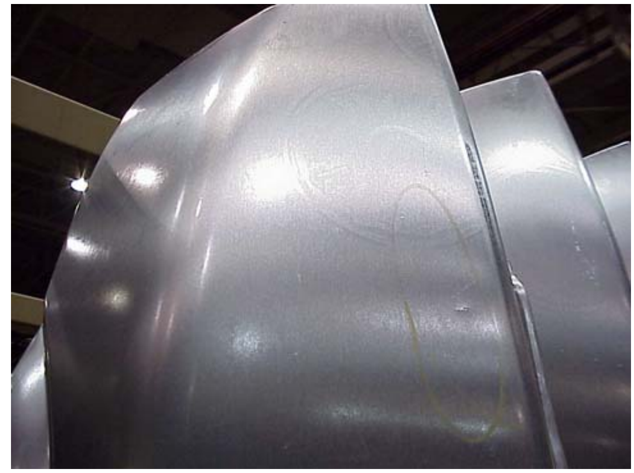

Fig. 3 Sliver imprint into the panel surface

Another specific study of trimming process quality was conducted in Ref 6. Experimental study of the lab samples and cross-sections of trimmed parts from production showed that hair-like slivers can be generated as a result of the fracture development from the upper trim steel. Bending of the offal causes a small tongue to be sheared off from the offal and produce the sliver. This mechanism was observed for wide variety of clearances between the shearing edges and cutting angles. Study of the sheared surface of production exterior panels led to the conclusion that slivers can be formed as local burrs on the part due to the 3D character of the production trimming process. In order to accomplish high quality of the trimmed edge and prevent generation of slivers, it was suggested to control the clearance between the shearing edges within several percents of the material thickness and also to machine a small radius on the upper shearing edge. The small clearance prevents formation of burrs and possible splits from trimmed surface in stretch flanging and hemming operations, while a small radius on the upper trim steel prevents separation of slivers from the top of the offal. However, this approach still requires accurate tooling alignment and may be difficult to implement for parts with complicated geometry.

In order to address the majority of issues mentioned above, a new robust trimming process involving elastic scrap support and preferential mechanism of fracture development from the lower trim edge was developed (Ref 7, 8). The objective of the research described in this article is to demonstrate the robustness of the process and to study its performance in wide range of trimming conditions including variation of clearance, radius of the upper trimming edge, cutting angle, stretching behavior of the trimmed edge, and performance of the robust process compared to conventional trimming process after a significant number of cuts.

2. Conventional and Robust Trimming Processes

In a conventional trimming process shown in Fig. 1, fracture initiates mostly from the upper trimming edge, as was discussed in detail in Ref 7. The fundamental reason of this phenomenon is that even for very small gaps between the shearing edges, bending of the scrap still takes place. It occurs because the load is distributed along the area of the blank-with-die contact, as is schematically shown in Fig. 4. Accordingly, even very small gaps between the shearing edges are not able to prevent the scrap from bending. This can be illustrated by an experimental result on partial separation of the part and scrap produced with 2% of the material thickness clearance using 0.93 mm sheet of aluminum alloy 6111-T4. For larger clearances (above 5%), this reason leads to development of a crack from the upper shearing edge through the whole thickness and generation of the burr width approximately proportional to the clearance value between the shearing edges (Ref 7). Some variation from such a proportion may be due to a change of the crack inclination angle to the blank surface.

The classic mechanism of fracture (Ref 1) where cracks from both upper and lower shearing edges propagate toward each other may only be provided for very small clearances, for example 2% as shown in Fig. 5. This classic mechanism was modified in Ref 3-5 by providing a specific angle of the blank inclination to the trimming direction between 15 and 25° and fairly accurate clearance below 15% that the crack from the upper trim steel would arrive to the lower trim edge rather than to the free surface of the blank. This approach allows larger, but still rather accurate clearance. Also, the inclination of the blank to the trimming direction (or cutting angle α, Fig. 1) is often defined by the part design rather than by the choice of die designers. Adjusting the cutting angle in one area of the part by turning the blank to a certain angle may create inappropriate trimming conditions in other areas of the part. Therefore, the main emphasis of the current research effort targeted the process appropriate for a wide variety of trimming conditions. Fundamental understanding of bending of the scrap as a root cause of the majority of trimming imperfections including burrs, slivers, and even splits occurring from the trimmed surface in stretch flanging and stretch hemming processes led to the development of robust trimming process (Ref 8). This process is schematically shown in Fig. 6a for perpendicular trimming when cutting angle is equal to zero and in Fig. 6b for the trimming conditions when the cutting angle may vary in between 0 and 45°. Two major points of difference distinguish the newly developed trimming process from the conventional trimming process: an elastic scrap support is added to the die design, and the upper shearing edge is fabricated dull to achieve the targeted mechanism of separation. The fundamental concept of the robust trimming process is to have fracture of the blank always propagated from the lower shearing edge through the whole thickness. It may propagate to the free upper surface of the blank, in which case, the role of the upper shearing edge is to drive the material of the blank down. It may also propagate toward the upper shearing edge. In both cases, the mechanical support of the offal prevents bending of the blank and creates conditions similar to pure shear, such that the fracture propagates through the blank as shown in Fig. 7 without opening the crack. This fracture mechanism also prevents creating the tearing conditions that take place in conventional trimming process (Fig. 8), while the offal is rotating being driven by a bending moment.

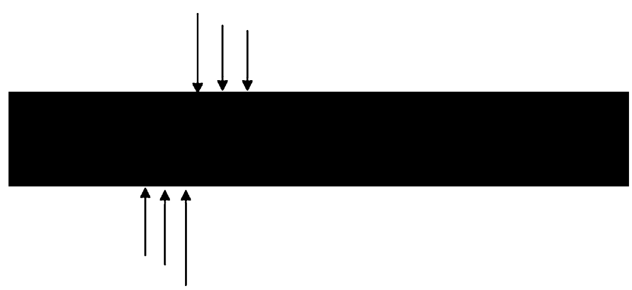

Fig. 4 Distribution of trimming forces leading to bending of the offal even when the clearance between the shearing edges is equal to zero

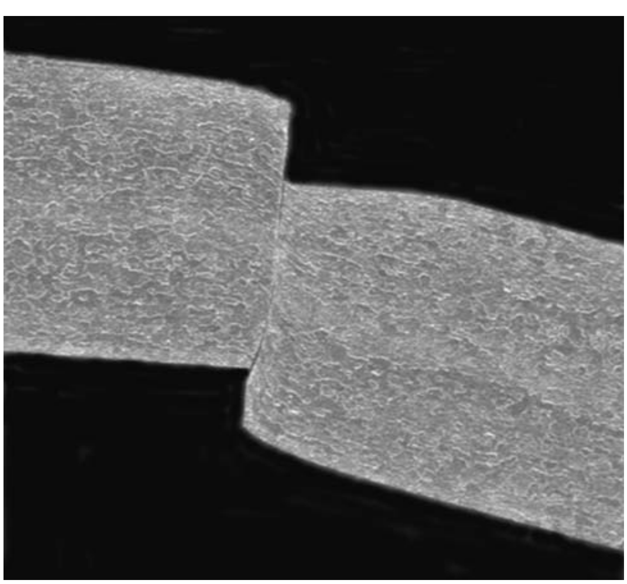

Fig. 5 Bending of the offal of the sample trimmed with 2% clearance between the shearing edges

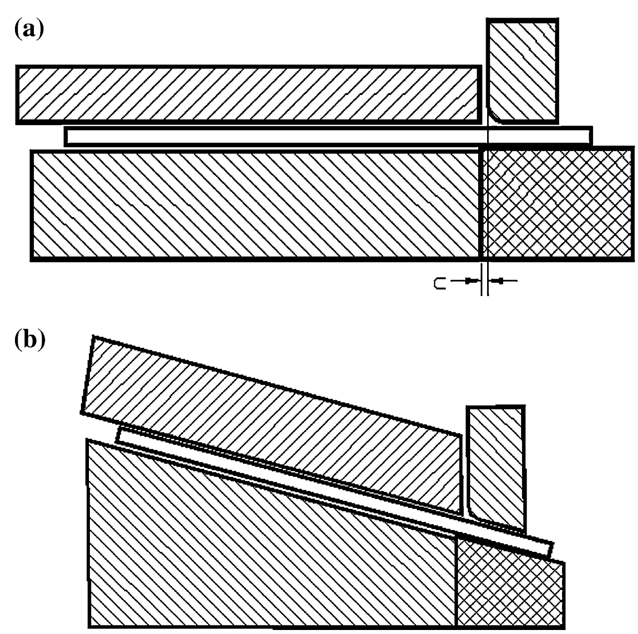

Fig. 6 Robust trimming process: (a) with no cutting angle and (b) with cutting angle α

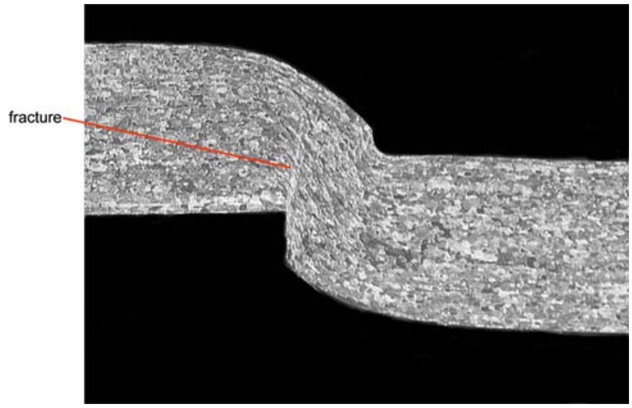

Fig. 7 Fracture propagation in robust trimming process

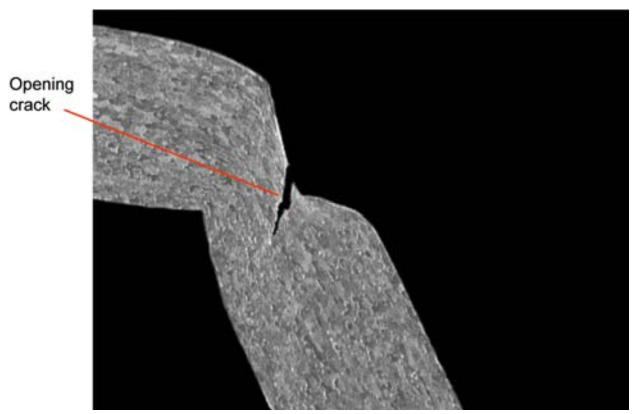

Fig. 8 Fracture of the sample observed in conventional trimming process with the large clearance

3. Experimental Technique

In an attempt to simulate production conditions, aluminum sheet AA6111-T4 0.93 mm thick was used for this experimental study. The sheet was cut into strips of 50 mm wide and 300 mm long. Strips were clamped using four bolts, which simulated the clamping pad of the production trim die. Each strip was sheared into samples about 12 mm long. These samples were then collected and their cross-sections were prepared. In most cases, one side of the piece represented the part side of the trimmed surface, and the other showed the offal side of this surface. In order to exclude edge effects, the cross-sections of trimmed samples were prepared in the center. Cross-sections of samples were polished, etched, and observed with optical microscopy.

To analyze the mechanism of crack propagation and scrap from part separation, partial trimming was employed. The process was interrupted prior to final separation. Partially sheared samples were then polished and analyzed.

The experimental tooling used in this study is shown in Fig. 9. It was built on a standard die shoe (432 mm long, 280 mm wide, 305 mm high) including a steady lower plate and movable upper plate guided by four columns and attached to four nitrogen cylinders able to return the upper plate to its original position. The upper and lower steel blocks were attached to the corresponding plates with bolts and pins. The actual tools designed as the punch and die inserts were attached with the screws to the upper and lower steel blocks. These inserts were fabricated from the plates of oil-hardenable steel. They were machined, ground, and heat-treated to HRC60. In order to have both inserts parallel to each other and provide identical trimming conditions along the trim line, the upper and lower steel blocks were mounted parallel using a special temporary block with accurately machined and ground parallel surfaces simulating the inserts. This measure established pin locations for the upper and

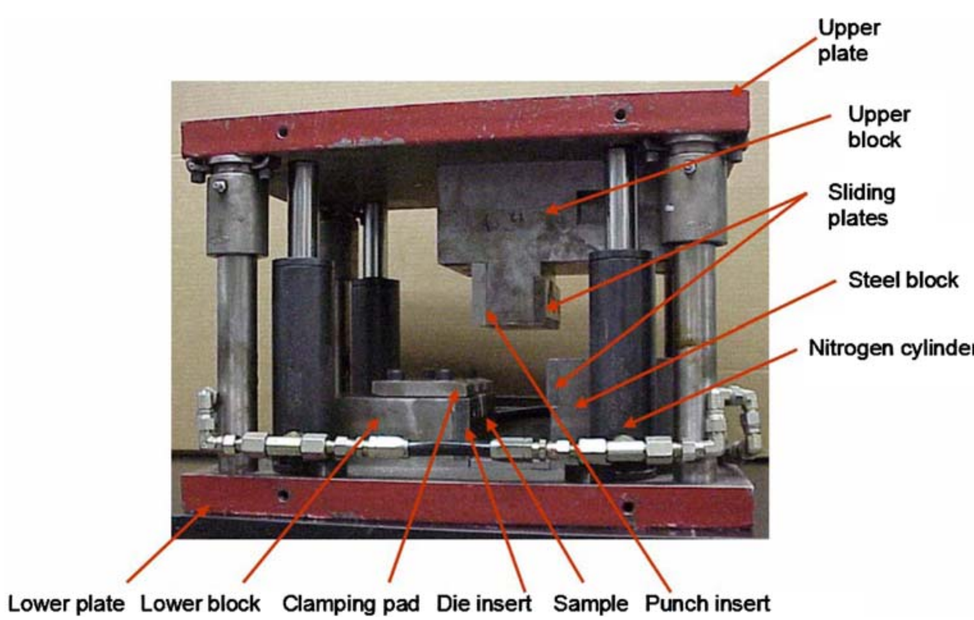

Fig. 9 Laboratory trimming die

lower steel blocks such that the inserts would be parallel. In order to increase the stiffness of the upper block and to prevent horizontal movement, an additional stiffening steel block was attached to the lower plate. To facilitate the upper block sliding along the surface of the stiffening block, special sliding plates were mounted on both blocks and accurately adjusted with shims.

Trimming and tensile tests were conducted using an Instron testing machine, Model 1125. For trimming experiments, the speed was 0.5 mm/s; for partial trimming the speed of the ram was lowered to 0.1 mm/s.

4. Influence of Trimming Conditions on Quality of Trimmed Surface

An experimental study was conducted to determine variation of trimming conditions in order to evaluate the robustness of the technology with respect to cost reduction of a trimming die. To accomplish accurate clearance between the shearing edges often requires extensive maintenance, which gets complicated with repeated trimming as the applied loading affects die clearance. Therefore, developing the process with a significantly wider "window" of trimming clearances is a step toward making trimming dies more affordable. Since the effect of the clearance on quality of the sheared surface and burr generation has been widely discussed in the literature including Ref 1, 2, 6, and 7, the results on the quality of trimming in conventional process are omitted in this article. For the robust trimming process, influence of the clearance was studied for often used perpendicular trimming (Fig. 10). The lower trimming edge was sharp, while the upper trimming edge had a radius of 0.025 mm (0.010 in.). Dulling the upper shearing edge and creating an elastic support caused fracture to develop from the lower shearing edge. This concept eliminated burrs and significantly improved dimensional stability of parts. Some variation of the clearance as a result of tooling fabrication and alignment in robust trimming results in some changes from the offal side of the trimmed surface. As emphasized earlier, the burr width in conventional trimming processes is proportional to the trimming clearance. Similarly, the width of the burr on the offal in the developed process is proportional to the trimming clearance. However, the burr on the offal side does not affect the quality or dimensional accuracy of the part, and therefore is not a problem. By eliminating the major burr issue, the robust trimming process also addressed the sliver generation problem. As was shown in detail in Ref 6 and 7, slivers usually separate from the contact area of the blank with the upper trimming edge during offal bending or from the contact area of the blank with the lower shearing edge, where local burrs can get separated. In the robust process, the burr on top of the offal side is strongly dependent on the radius of the upper trim die, and no local burr is generated on the lower trim edge.

It is noted that variation of trimming clearance in the robust process does change the shape of the part. Variation of the angle between the blank plane and the sheared surface can be observed in Fig. 10. This angle is visibly different from 90° for 20, 30, and 40% clearance. However, further increase of the clearance brings the sheared surface close to the perpendicular position similar to that at 2% clearance. Another factor that changed with the growth of the gap between the shearing edges is the rollover on the top of the blank, which visibly increased with the growth of the clearance.

Robustness of the developed trimming technology was also verified from the perspective of the radius which should be fabricated on the upper trimming die. Results on trimming with various radii of the upper trim edge (0.25, 0.5, 1, 1.5, 2, and 2.5 mm) are shown in Fig. 11 for 30% clearance. It can be observed that no burr or sliver generation took place. From a previous study (Ref 7), it was confirmed that the radius of 0.12 mm was also feasible for the robust trimming process.

Variation of the trimming angle for the clearance of 30% also demonstrated robustness of the developed technology (Fig. 12). However, it should be indicated that the quality of the sheared surface degraded with increasing cutting angle, and further modifications are necessary (Ref 8) to conduct trimming with the cutting angles exceeding 45°.

In order to confirm the validity of the developed robust process for high volume production, the influence of the potential tool wear was estimated by conducting 20,000 tests using an automated laboratory mechanical press. Comparison of the samples produced by the robust trimming process employing new trimming die with the samples produced after 20,000 cuts is shown in Fig. 13. Comparison of the samples indicates that some dulling of the sharp lower shearing edge took place, resulting in a very small burr generated on the part side.

5. Influence of Trimming Conditions on Ability of the Trimmed Blank to Stretch

In a number of previously published studies, it was emphasized that sheared surface quality may significantly affect formability of the blank in the adjacent area. In Ref 1, a direct link between the burr height and the maximum elongation of the sheared edge was established. In Ref 9-11, the effect of the sheared edge on formability was studied for a hole expansion test. The direct connection of these results to the stretch flanging process should be further explored, even though the clearance between the shearing edges in the hole piercing process, conducted prior to the hole expansion, was rather wide (Ref 9-11). Burrs observed on the hole side were significantly smaller (Ref 9) than in the conventional trimming process. Potentially, this occurred due to significantly larger bending stiffness of the blank being pierced compared to conventional trimming. Also, the choice of the diameter of the hole in the hole expansion test may affect the results on formability. In Ref 9-11, the hole diameter was 10 mm. Therefore, a different testing procedure was chosen in this study based on a significantly simpler method of trimmed surface preparation. While standard tensile tests of the sheet material is conducted by stretching a "dog bone" sample with an appropriate transition zone from the clamps to the stretched

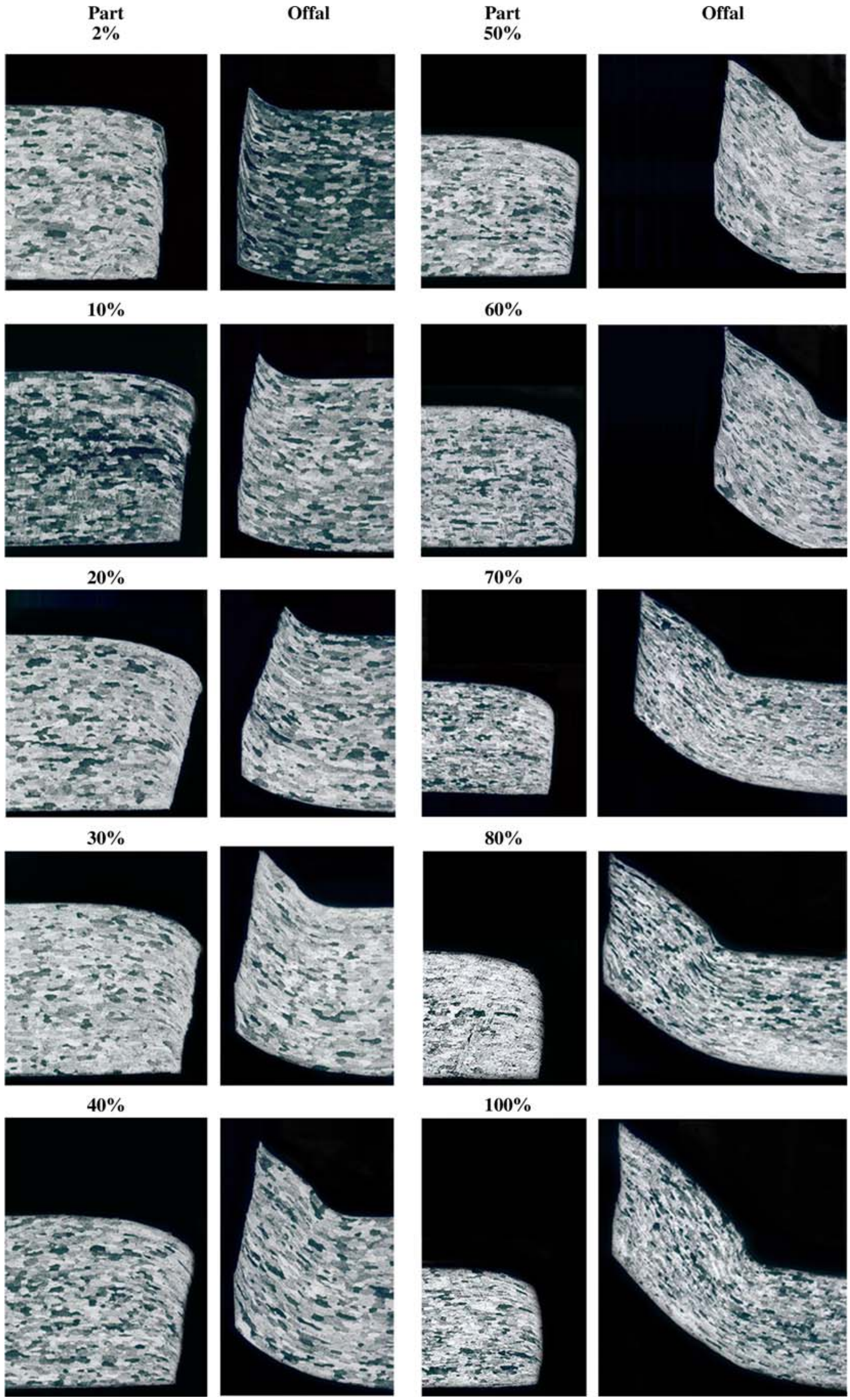

Fig. 10 Influence of the trimming clearance on the shape of part and offal separated in robust trimming process

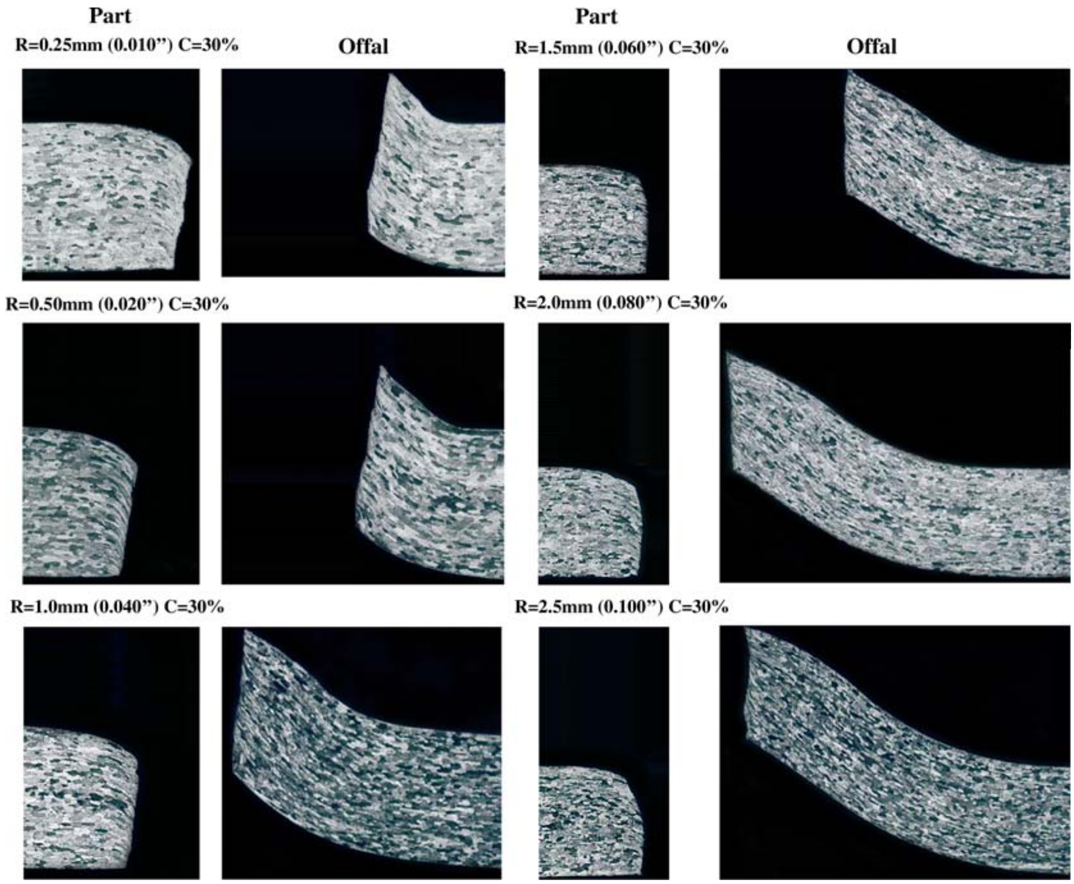

Fig. 11 Influence of the radius of the upper trim edge on the shape of the part and offal after robust trimming process with the clearance of 30% of the material thickness

area, a ''half-a-dog bone'' sample design was suggested to test the stretching ability of the blank area adjacent to the trimmed surface. The sequence of the sample preparation and testing follows (Fig. 14):

1. Samples were trimmed from the strip 300 mm long and 75 mm wide. Usually the length of the sample was 12.7 mm. The trimmed surface of the part is shown with dashed lines in Fig. 14. Solid lines indicate the offal side of the trimmed surface.
2. ''Half-a-dog bone'' shape on the offal side was fabricated using electrical discharge machining (EDM) technique in order to prevent localization of the deformation near the area of clamping.
3. Samples were stretched parallel to the trimming line.

EDM the scrap side of the trimmed strip eliminates an option that fracture of the strip during the tensile test initiates from this area where the burr may occur during trimming stage of a sample preparation. Moreover, the EDM technique removes the volume of metal where plastic deformation took place during trimming.

Three different modes of fracture (Fig. 15) were observed in these tensile tests:

Mode 1—typical fracture observed in standard tensile tests, when fracture is initially localized as shear bands and then separation happens with a typical angle defined by material anisotropy;

Mode 2—slow opening of the crack perpendicular to the tensile direction.

Mode 2+1—combination of modes 2 and 1, when fracture starts from mode 2, but then finalized at mode 1 since the material is close to its limit of elongation.

For modes 2 and 2+1, we usually observe multiple cracks starting from local defects on a trimmed surface, which indicates that this mechanism is not defined by a single defect on a trim die.

Analyzing the experimental data, we have seen a clear link between the mode of fracture and the obtained elongation. The best elongations were obtained for mode 1, while for mode 2 they were the worst. Mode 2+1 provided elongation values smaller than mode 1 but larger than mode 2. The results on total

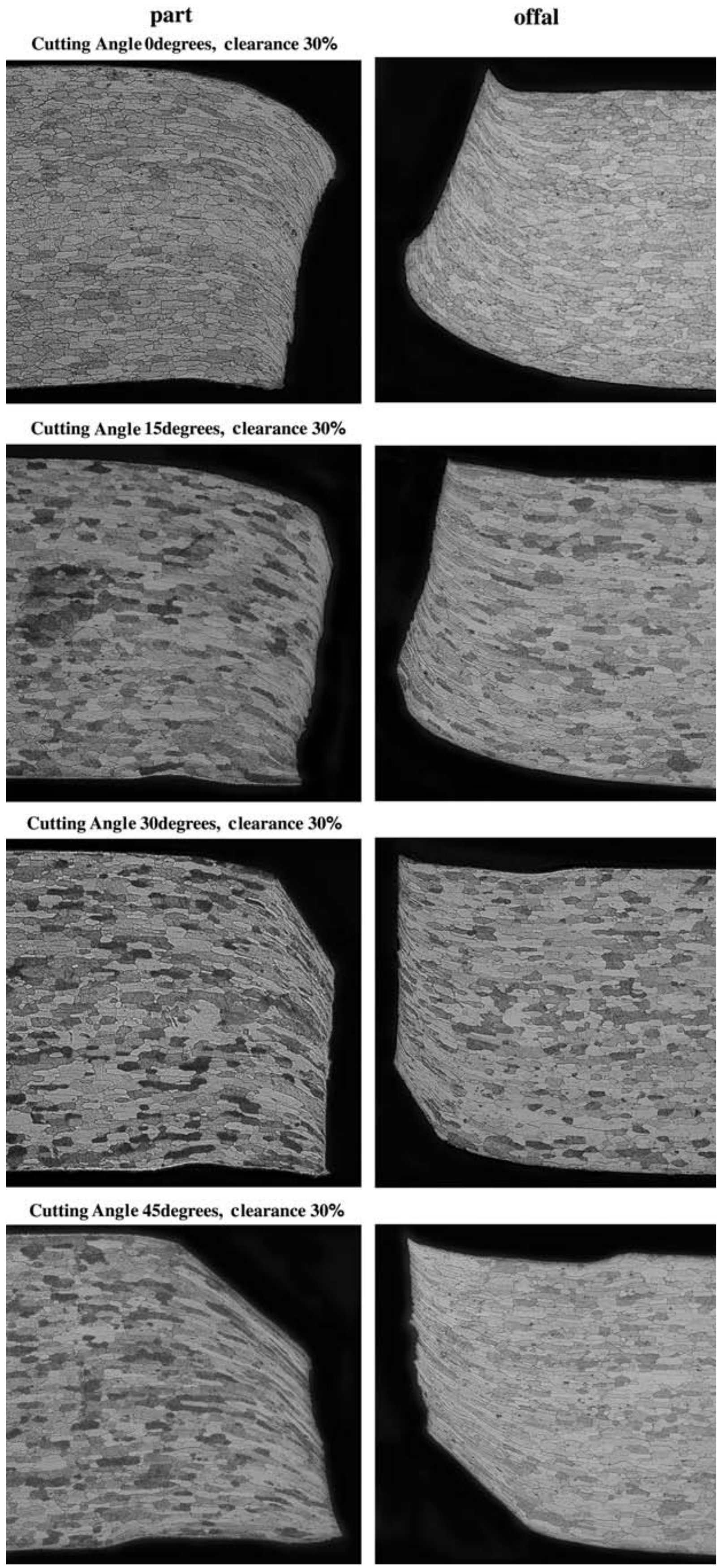

Fig. 12 Influence of the cutting angle on the shape of the part and offal after robust trimming process

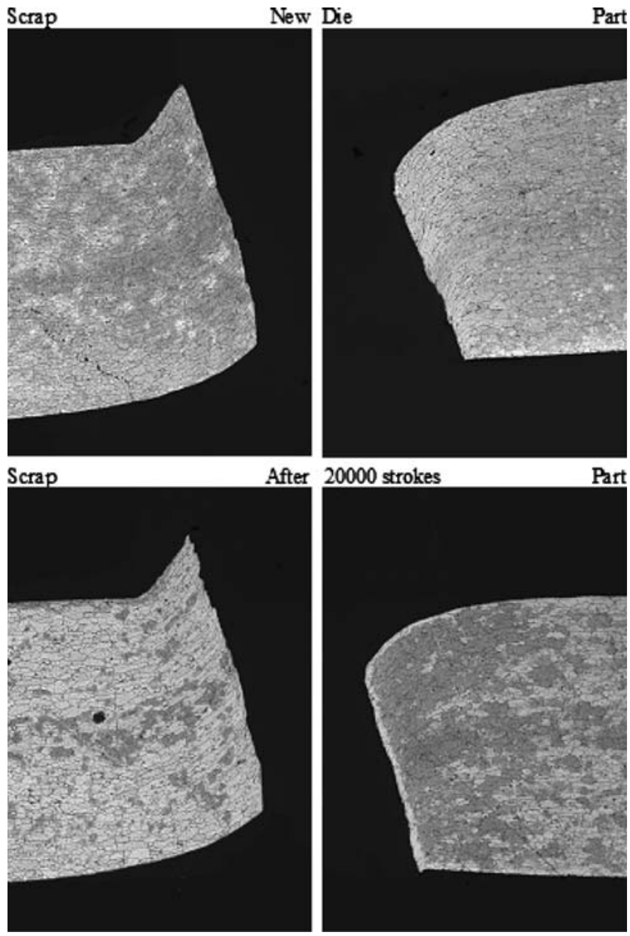

Fig. 13 Influence of the tool wear after 20,000 trims on the shape of part and offal after robust trimming process

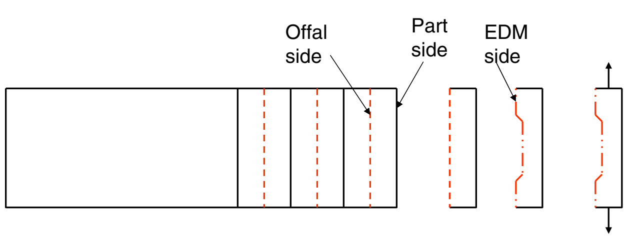

Fig. 14 Steps of the experimental study of the trimmed edge ability to stretch

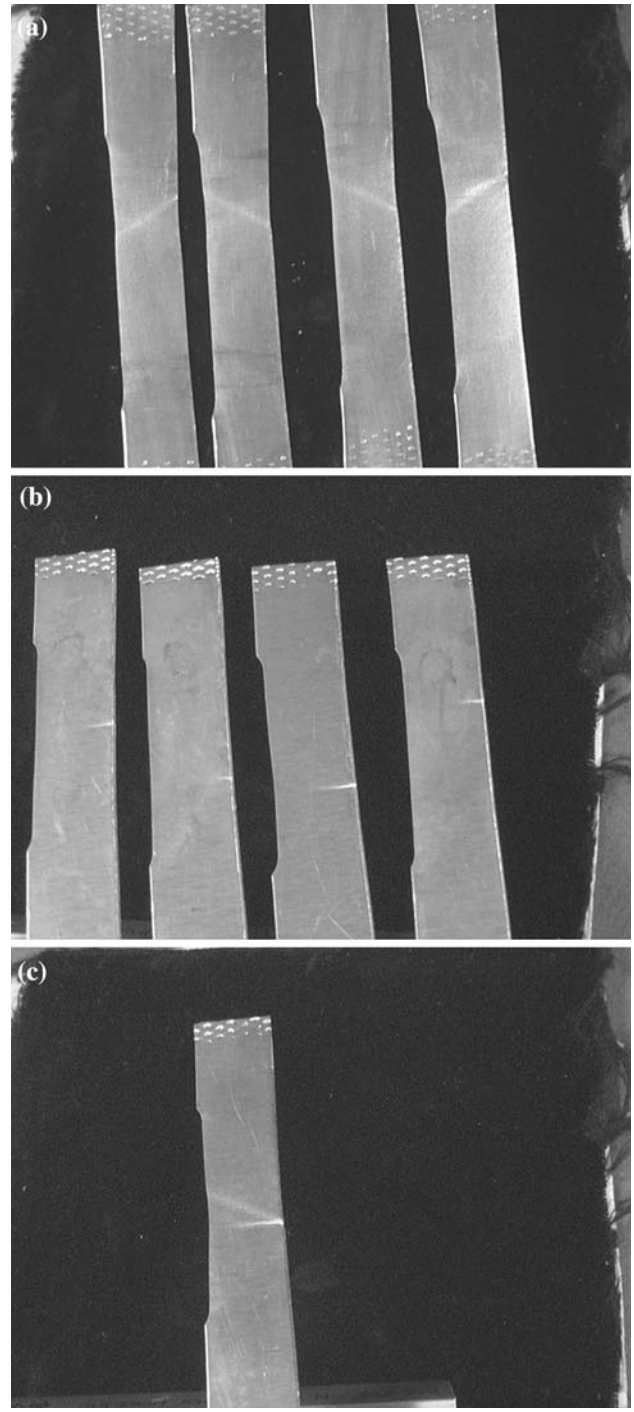

Fig. 15 Modes of fracture of "half-a-dog bone samples" representing stretching of trimmed surface: (a) traditional fracture mode in a standard tensile test, (b) crack opening perpendicular to the trimmed surface, and (c) mixed mode

elongation of trimmed samples are shown in Fig. 16 comparing the conventional trimming and robust trimming process. Mode 1 was observed for the robust trimming process and after trimming with small clearances in the conventional trimming process. Mode 2 was observed for stretching of the majority of samples after conventional trimming process with the clearance of 10% and above.

6. Conclusions

1. Experimental study of a recently developed robust trimming process indicated that it provides capability to trim parts in wide range of clearances between the shearing edges, radii of the upper shearing edge, and cutting angles without generating burrs.
2. Analysis of trimmed edge ability to stretch parallel to the trimmed surface indicated that robust trimming process provides stable results for variety of clearances between the shearing edges, while the study of the conventional

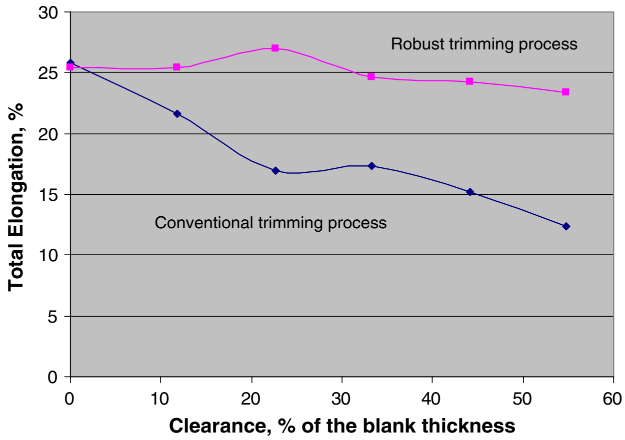

Fig. 16 Influence of the clearance between the shearing edges on total elongation of the trimmed edge

trimming process demonstrated significant reduction of trimmed edge formability with the growth of the trimming clearance.

References

1. D.A. Smith, *Die Design Handbook*. Society of Manufacturing Engineers, Dearborn, MI, 1990
2. L.K. Gillespie, *Deburring and Edge Finishing Handbook*. Society of Manufacturing Engineers, Dearborn, MI, 1999
3. M. Li and G. Fata, Sliver Reduction in Trimming of Aluminum Autobody Sheet, SAE Paper 1999-01-0661, 1999
4. M. Li, An Experimental Investigation on Cut Surface and Burr in Trimming Aluminum Autobody Sheet, *Int. J. Mech. Sci.*, 2000, **42**, p 889–906
5. M. Li, Micromechanisms of Deformation and Fracture in Shearing of Aluminum Alloy Sheet, *Int. J. Mech. Sci.*, 2000, **42**, p 907–923
6. S. Golovashchenko, Analysis of Trimming of Aluminum Closure Panels, *J. Mater. Eng. Perform.*, 2007, **16**, p 213–219
7. S. Golovashchenko, A Study on Trimming of Aluminum Autobody Sheet and Development of a New Robust Process Eliminating Burrs and Slivers, *Int. J. Mech. Sci.*, 2006, **48**, p 1384–1400
8. S. Golovashchenko and M. Blodgett, Apparatus for Trimming Metal. US Patent 7,197,970 B2. April 3, 2007
9. A. Konieczny and T. Henderson, On Formability Limitations in Stamping Involving Sheared Edge Stretching, SAE Paper 2007-01-0340
10. M. Shi and X. Chen, Prediction of Stretch Flangeability Limits of Advanced High Strength Steels Using the Hole Expansion Test, SAE Paper 2007-01-1693
11. J. Chintamani and S. Sriram, Sheared Edge Characterization of Steel Products Used for Closure Panels Applications, SAE Paper 2006-01-1589