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Analysis of Trimming of Aluminum Closure Panels

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Pieces of aluminum are generated during trimming of aluminum body panels. Commonly referred to as slivers, these pieces can be imprinted into the surface of stamped panels. This may require metalfinish of every stamped exterior panel. The objectives of the present study were to investigate the influence of trimming conditions on the quality of trimmed surfaces and determine modification of the trimming process to eliminate slivers. Suggested solution is to machine a small radius on the upper shearing edge and to control the clearance between the shearing edges within several percents of the material thickness.

Keywords aluminum, automotive, stamping

1. Introduction

In order to reduce vehicle weight, modern product design and manufacturing often utilizes a wide variety of materials including aluminum alloys. These alloys often present difficulties when subjected to manufacturing processes originally designed for low carbon steel. One such manufacturing area where difficulties may arise is in trimming operations of automotive exterior and interior body panels. Aluminum alloys often demonstrate different technological behavior due to differences in mechanical and surface properties and mass density when subjected to trimming operations. The mechanism of separation in shearing operations (such as blanking, piercing, trimming, etc.) is often considered as a result of fracture initiation from both upper and lower cutting edges of the shearing die (Ref 1). If the clearance between the shearing edges is suitable for the material being cut, these fractures will spread toward each other and eventually meet, causing complete separation. This "ideal" mechanism of separation is often very difficult to accomplish in trimming dies of automotive panels.

The practical experience of stamping of aluminum body panels indicates that small pieces of aluminum are generated during the trimming process. Typically, for 1-mm thick Al sheet, these pieces are 0.05-0.2 mm in cross-section and 5-40 mm in length. Commonly referred to as slivers, they are highly undesirable, since they often adhere to the blank surface and get distributed to the dies following the first trimming operation (second trimming die and a flanging die). The accumulation of slivers on both the die and blank surfaces can result in an unacceptable surface finish. The slivers located on either the dies or the blanks can be forced into the blank surface, as it can be seen in Fig. 1. This problem, in addition to the higher cost of aluminum compared to steel, is one of the main obstacles preventing widespread usage of aluminum in auto body panels.

Known techniques 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 blowing slivers with compressed air, or manually cleaning them from the die surface are common. The removal of slivers from the dies and metalfinishing 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 stamped part surface is often required and additional metal work may be conducted to repair indentations caused by the slivers. These efforts add to the cost and time of product manufacturing and may lead to an increase in the number of rejected parts if repair is not feasible.

Another factor influencing panel quality is the production of burrs during trimming. Traditionally, the overall quality of the part after any shearing operation is defined by the height of burrs on a sheared surface in addition to dimensional accuracy and absence of splitting. 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 metalfinish operation and conducted manually. Therefore, deburring adds significantly to the cost of a stamped part.

Existing die design recommendations attempt to limit the production of burrs through accurate alignment of the upper and lower edges for shearing operations like trimming, blanking, piercing, etc. Accurate alignment of the upper and lower shearing edges is required to obtain acceptable surface quality: the clearance between the shearing edges should be less than 4.5-6% of the material thickness (Ref 1). Shibata (Ref 3) recommends a clearance set 0.04-0.08 mm irrespective of sheet thickness, while Wanibuchi (Ref 4) sets a clearance between the shearing edges of 0-5% of the material thickness.

An additional factor reducing throughput and increasing the percentage of rejected aluminum panels is defined by the presence of splits developing from trimmed surface in stamping and assembling operations such as flanging and hemming. An example of such a split is shown in Fig. 2.

The objectives of this article are: (1) to study the influence of trimming conditions on generation of slivers, burrs, and

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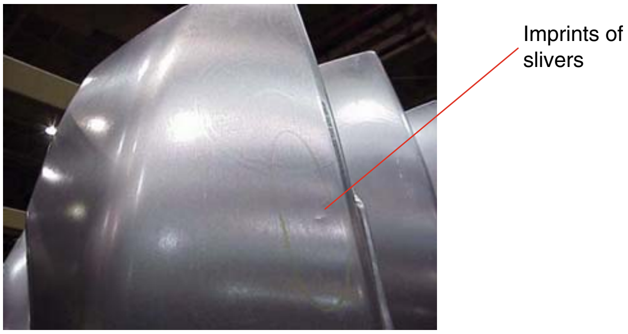

Fig. 1 Imprints of slivers into stamped panels

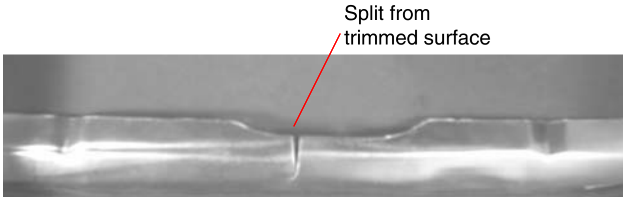

Fig. 2 Split from trimmed surface generated due to stretching along the trimmed surface

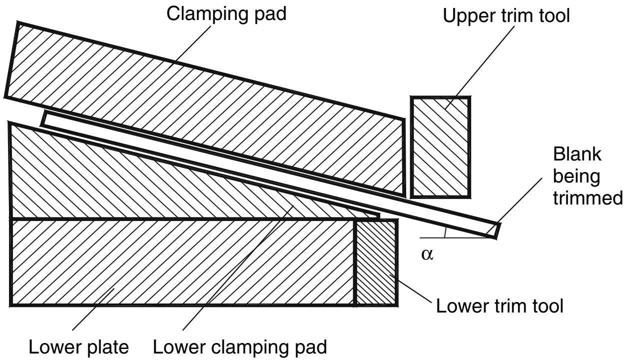

Fig. 3 Schematic of the trimming process

splits developing from trimmed surface; (2) to develop and verify a trimming process, eliminating slivers, burrs and splits from trimmed surfaces and allowing an increase in production rate of aluminum panels to a level similar to steel.

2. Experimental Technique

Schematic of the conventional trimming process is shown in Fig. 3. In order to simulate different trimming conditions in current experimental study, the clearance, *c*, between the shearing edges, the radius of the shearing edges, and the cutting angle, α were varied. To conduct this study, an experimental fixture shown in Fig. 4 was designed and constructed. For accurate alignment of the upper and lower trimming tools, a die shoe with two guiding columns was used. The upper and lower trim tools were fabricated as inserts and bolted to the upper and lower blocks correspondingly. The upper and lower blocks were mounted on the upper and lower plates of the die shoe using bolts and pins. The trimming tools were machined from oil-hardenable flat stock 12.7 mm thick. The clearance between the upper and lower trim tools was adjusted to be uniform along the shearing line with the accuracy of about 0.01 mm. This clearance was varied by using a set of shims, which were machined from cold rolled calibrated steel plates by cutting them out of plate and drilling holes to install them as spacers between the upper trimming tool and the upper block (Fig. 4). In addition, the horizontal stiffness of the tool was increased by mounting a steel block on the lower die. This block and the upper block were adjusted to slide one along the other using sliding plates with almost no clearance when the press ram moves down. When horizontal forces are applied during the shearing process, this block prevents the upper block from shifting to the right. In order to vary the cutting angle α, additional plates were machined to clamp the part at angle while the same trim tools were used for different α. In this article the variation of α is limited by α = 15° and 0°. Two sets of clamping pads were machined to adjust tooling for selected levels of α: the case of α = 15° is shown in Fig. 3 and the case of α = 0° is shown in Fig. 4. In an attempt to simulate production conditions, aluminum sheet AA6111-T4 0.93 mm thick, often employed for exterior panels in automotive industry, was used for this experimental study. The sheet was cut into strips 50.8 mm wide and 305 mm long. Originally, strips were clamped using four bolts, which simulated the clamping pad of the production trim die. Simulating the trimming process, 12-mm long offal samples were trimmed from a 50.8-mm wide strip. After each trimming experiment, the strip was unclamped and advanced for another 12.7 mm. These samples were then collected and their cross-sections were prepared: one side of the piece represented the part side of the trimmed surface, and the other side showed the offal side of the trimmed surface. For metallographical analysis of the blank structure, the cross-sections of these samples were prepared perpendicular to the trimming line. Samples were cut in the middle in order to exclude the edge effects. Further preparation of the samples for metallographical analysis was the following. Cross-sections of parts and offals were mounted in a cylindrical block and filled with epoxy. They were then ground, polished, and etched. The solution, which provided good quality of etching for AA6111-T4 was 85% water, 10% sulfuric acid, and 5% hydrofluoric acid. An etch time of 15-20 s was used followed by washing in water and blowing with compressed air. The cross-sections of part and offal sides perpendicular to the trimming line were observed under a microscope, equipped with a video camera. This analysis led to the understanding of fracture initiation and defects generation mechanisms.

3. Discussion of Mechanisms of Generation of Burrs, Slivers, and Splits Developing from Trimmed Surface

As defined in previously published literature, clearance between the shearing edges is the most critical parameter affecting the quality of trimming. In order to understand the conditions upon which burrs, slivers, and splits from trimmed surface may occur, a set of experiments was conducted covering the following range of possible variation of clearance between the shearing edges and cutting angle: *c* = 2, 10, 21, 31, 42, and 52% for α = 0°, 15°, and 30°. Since mechanisms of fracture and defects generation have been similar in most combinations of parameters *c* and α, only typical cases are listed below. To define the mechanism of sheared surface formation in conventional trimming process, a number of interrupted tests and numerical simulation of the process were conducted. The analytical approach to the simulation of the trimming process (Ref 5) is based upon explicit integration procedure of equations of motion of elasto-plastic solid. The die was considered to be rigid, and Coulomb friction was taken into account. The boundary condition of rigid clamping was used in order to limit the number of elements at some distance to the left from the lower shearing edge (Fig. 5). The described approach was incorporated into a research code, which enabled the simulation of the trimming process with preferred fracture criterion and mechanism of crack propagation (Ref 5). The distribution of plastic strains in the blank for trimming with *c* = 30% and α = 0° is shown in Fig. 5. This distribution indicates that for relatively large clearance during indentation of shearing edges approximately the same amount of strains is produced from both edges. However, experimental results indicated that the initiation and the development of original cracks was from the upper trim tool even though both upper and lower steels had identical sharpness. This can be explained using the numerical model (Ref 5) of fracture propagation based upon damage criterion, which takes into account the influence of stress state history of deformation of each element.

$$\psi = \int_0^t \frac{\dot{\varepsilon}}{\varepsilon_{\mathrm{fr}}} \mathrm{d}t = 1$$

where $\dot{\varepsilon}$ is strain rate intensity; *t* is time; $\varepsilon_{\mathrm{fr}}$ is strain intensity at the beginning of fracture, which should be identified for a

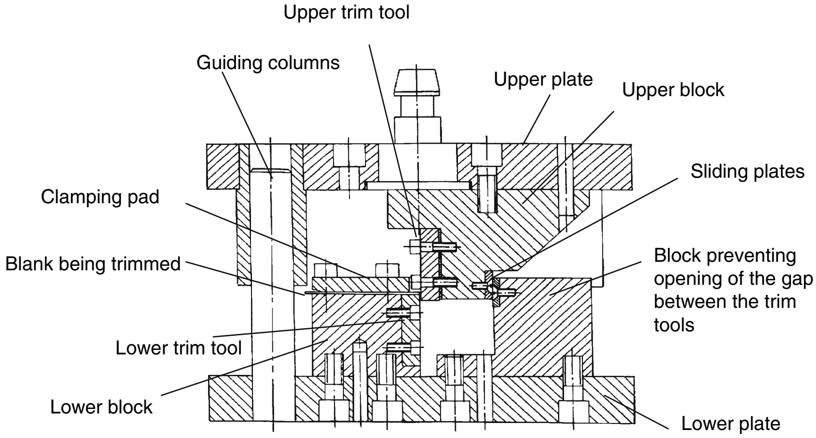

Fig. 4 Design of the tooling for the experimental study of trimming processes

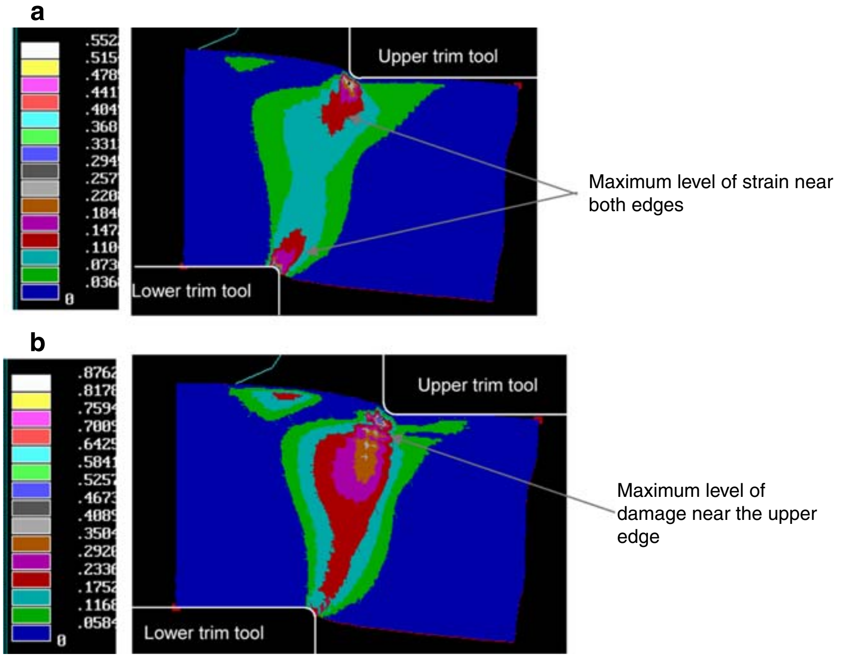

Fig. 5 Numerical results on plastic strains (a) and material damage ψ (b) distribution for conventional trimming with *c* = 30%

number of different tests where the ratio of the mean stress to the current yield stress σ_o/σ_s = const. As an example of such a test, Bridgeman tensile test with superimposed external pressure can be considered (Ref 6).

Having analyzed the mechanics of the trimming process, it becomes clear that bending of the offal changes the overall symmetry of the shearing process creating additional tension near the upper shearing edge and additional compression near the lower edge. It is known that almost every material has higher ductility in the compressive stress state than in the tensile stress state (Ref 6). This provides a qualitative explanation of the preferential development of cracks from the stretched area near the upper shearing edge as compared to the compressed area near the lower shearing edge. This explains the observed shapes of trimmed parts in Fig. 6 and the mechanism of crack propagation in Fig. 7. With increased clearance between the shearing edges, bending of the offal plays a more important role in the deformation mechanism. Analyzing the mechanism of the shearing edges indentation into the blank body, it is evident that bending takes place for any gap, even for a clearance equal to zero. Assuming that forces from the shearing edges are locally applied at the sharp edges, bending moment should be equal to zero. However, contact stresses are distributed along some area of the shearing edge and the blank. Therefore, a bending moment exists even for zero clearance.

Below the results of visual metallographical analysis of the sheared surface shape and trimming mechanism are discussed. As it can be seen from the cross-sections of parts for $\alpha = 15°$ shown in Fig. 6: a burr did not form only for 2% clearance while for the larger gaps, the burr width was growing with the increase of the clearance between the shearing edges. More detailed study of the fracture mechanism indicated that the initial crack starts a small distance away from the sharp corner of the upper trim tool. The area around this sharp corner is subjected to large plastic deformation. The deformation significantly exceeds the total elongation typically found in a tensile test for this material. This is possible due to compression of the material around the shearing edge. As it was earlier indicated, almost every material has higher ductility in the compressive stress state than in the tensile (Ref 6, 7). When the offal has been bent to a certain angle, some area of the blank goes out of contact with the shearing edge of the upper trim tool. This happens due to indentation of the shearing edge into the blank body and sliding of the shearing edge along the blank surface. Since that a small additional increment of deformation of the area, which went out of contact with the edge, becomes critical. Small additional strain without any compressive pressure spends all the material ductility, remaining after the initial indentation of the shearing edge into the blank body. This process results in the initiation of a crack from this zone and the generation of a tongue on the top of the offal side of the sheared surface, as seen in Fig. 7a for $\alpha = 0$. During further fracture development, the offal is bent down and the tongue is subjected to horizontal forces from the vertical wall of the upper trim tool. These forces break the tongue off the offal and generate the hairlike sliver, shown in Fig. 7b for the front view of the sheared surface of the offal. Our experiments indicated that opening the gap between the shearing edges from 2 to 65% of the material thickness results in increasing the offal bending angle. It leads to the growth of the burr height and width on the part side of the sheared surface for both $\alpha = 0$ and 15°. Separation of slivers from the offal is possible for all presented clearances including the accepted industrial practice of 10% and recommended intervals less than 5%. This can be also confirmed by the simulation results conducted for the clearance of 2% and $\alpha = 0°$. Crack initiation and propagation is illustrated in Fig. 8. The results of numerical

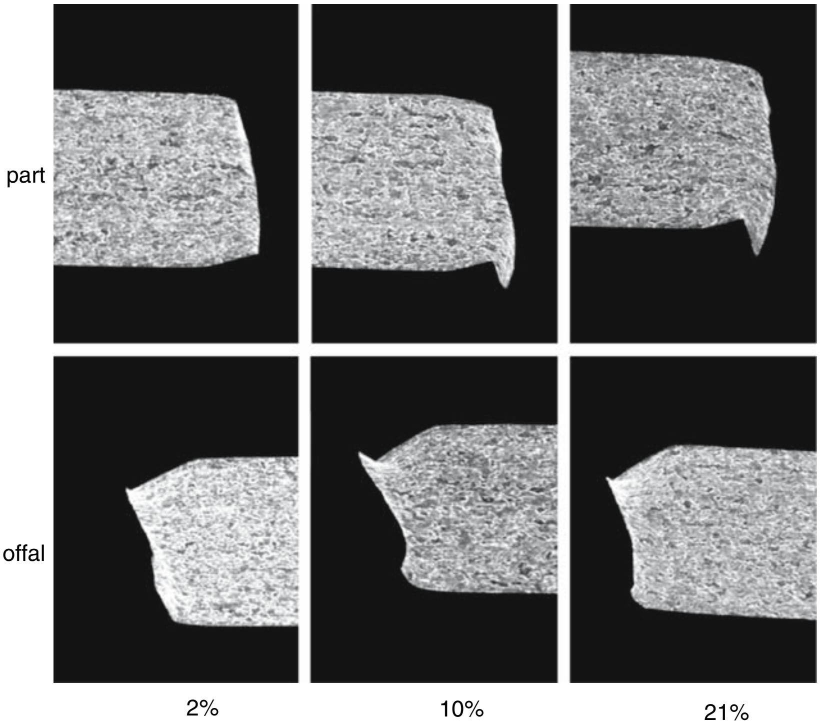

Fig. 6 Part and offal cross-sections after trimming with $\alpha = 15°$

simulation also confirm the formation of a small "tongue" on the offal due to the original crack initiation from the area where material comes out of contact with the upper shearing edge.

Validity of the described method of sliver formation was also confirmed for trimming of advanced high-strength steel (Ref 8). The shape of the trimmed surface, the number of separated slivers and their effect on surface quality varies for different materials. However, the general trend of the defect generation remains the same.

Observation of burrs along the trimmed surface indicates that they may be responsible for splits generated from trimmed surfaces if stretching is applied along the trimmed surface. Such a conclusion can be supported by the front view of the burr shown in Fig. 9. Even though all the results described in this article were obtained for aluminum alloy 6111-T4, it should be mentioned that very similar mechanism of splitting from a trimmed surface to the mechanism shown in Fig. 2 was also observed for the advanced high-strength steels DP500 and DP600 (Ref 8). The height of the burr is non-uniform along the line of trimming with some deep pockets which can serve as stress concentrators if stretching is applied parallel to this surface. In addition to being potential sources of splits in stretch flanging operation, burrs can also get separated from the trimmed part if there was a significant gradient of clearance along the trimming line. Due to the guillotine mechanism of shearing, these local burrs are subjected to additional forces, and they can be torn off from the part side of the sheared surface. An example of such an occasion is shown in Fig. 10 for a real production part. This observation suggested an additional mechanism of sliver formation.

Analysis of existing recommendations and conducted experimental study brings to the conclusion that burrs can be eliminated on the part side if the tooling alignment is improved by reducing the clearance to 6% of the material thickness. However, this approach cannot solve the major technological problem of sliver generation. The fundamental reason of this phenomenon is that even for very small gaps between the shearing edges, bending of the offal still takes place and small tongue on the top of the offal near the contact area with the upper trim steel is still generated. Similar conclusions can be drawn out from experimental data on trimming with $\alpha = 0°$.

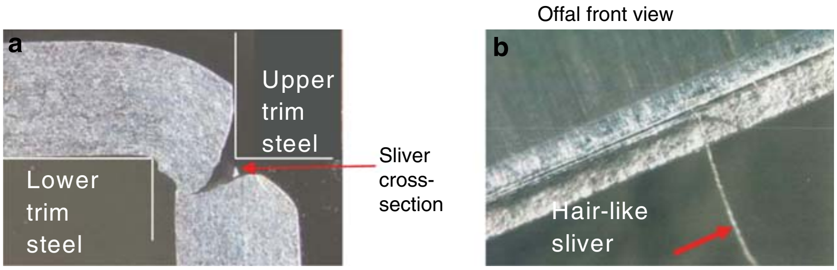

Fig. 7 Mechanism of sliver formation during trimming with $\alpha = 0°$: (a) cross-section of part (left side) and offal (right side); (b) front view of the offal with the sliver

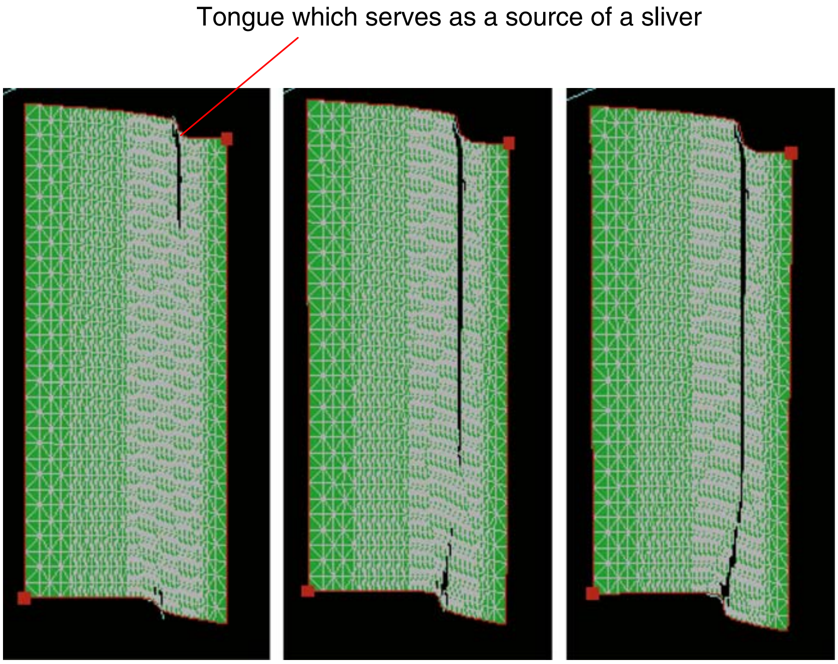

Fig. 8 Mechanism of crack propagation during trimming with $c = 2\%$ and $\alpha = 0°$

4. Modification of the Trimming Process

According to the above study on the conventional trimming process, bending of the offal is the root cause of both burr and sliver formation. In order to eliminate or significantly reduce these phenomena, the upper shearing edge was fabricated slightly dull. For trimming of blanks from 0.93 mm (0.038 in.) thick 6111-T4 aluminum sheet, a radius of 0.12 mm (0.005 in.) served this purpose. Such a modification does not change the mechanism of trimming: bending of the offal creates enough stretching that the major crack still propagates from the upper shearing edge. However, increasing the radius makes the tongue on top of the offal side significantly stronger, so, during rotation of the offal, the tongue does not separate. Cross-sections of the part and offal after trimming with a dull upper shearing edge ($R = 0.12$ mm), are shown in Fig. 11. These results indicate that burr formation is still an issue; however, it can be resolved by controlling the clearance. As it can be seen in Fig. 11, for 2% clearance there is no burr observed on the part side. Therefore, such trimming process can eliminate all three undesirable effects: generation of slivers, burrs, and splits from trimmed surface. These modifications can be implemented into existing trim dies, making it attractive for manufacturing engineers (Ref 9). This trim die design is suitable for parts with relatively simple geometry, for example hoods, where suggested modification may represent very effective and economical solution.

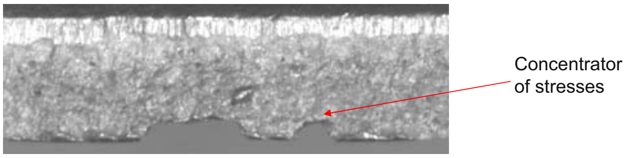

Fig. 9 Front view of the burr on the part side of the sheared surface

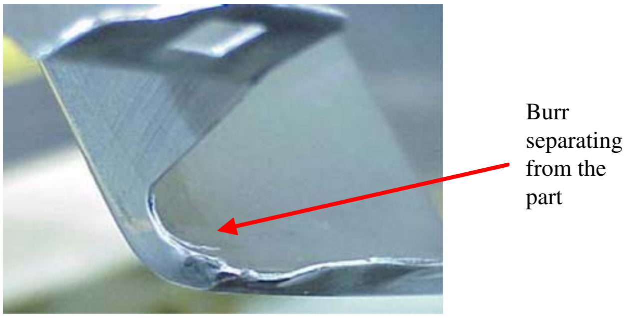

Fig. 10 Separation of the local burr from the trimmed part

In order to understand the robustness of the suggested process in terms of the upper shearing edge geometry, additional experiments were conducted with 0.24 and 0.48 mm radii of the upper shearing edge. In both cases good quality of the trimmed surface was observed for rather small clearances of 2-5% of the material thickness. The earlier observed "tongue" on top of the offal had no tendency for separation for both radii. However, the trimming force had a trend to increase. For the recommended clearance of 0.12 mm, the maximum trimming force was only 10-15% larger than in

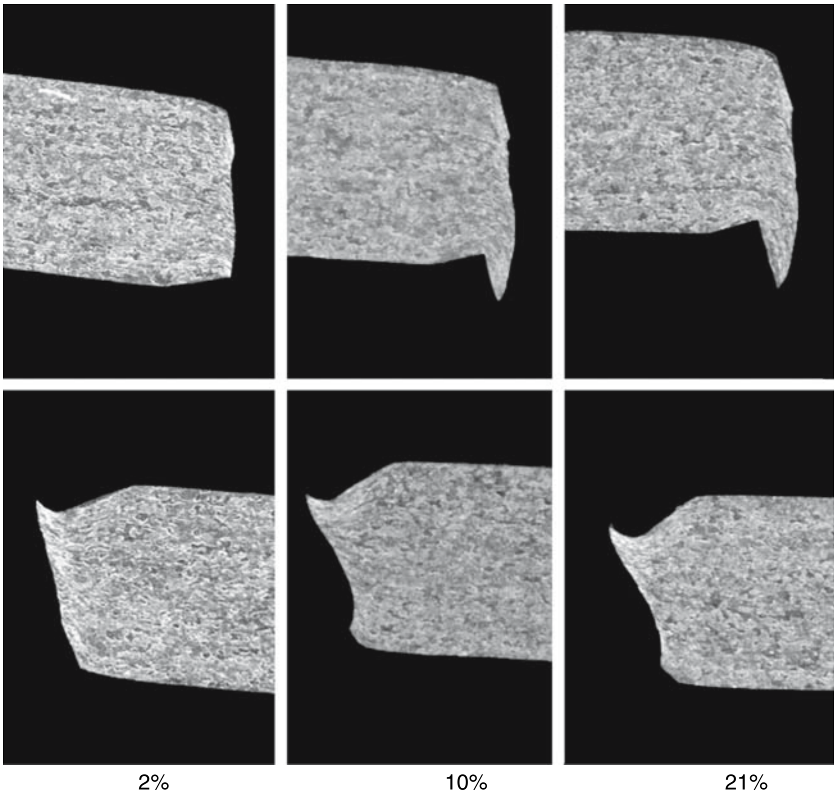

Fig. 11 Cross-sections of part and offal after trimming with dull upper shearing edge

case of both sharp shearing edges. Increasing the upper shearing edge radius to 0.24 and 0.48 mm resulted in an increase of the maximum force 14-27% and 27-40% correspondingly depending upon the clearance between the shearing edges. Also, increasing the upper shearing edge resulted in significant growth of the displacement of the upper trimming edge, corresponding to the point of separation of the part from the offal. Such a trend potentially may increase the wear of the sharp lower shearing edge. Therefore, a minimum radius of 13% of the sheet thickness resulting in appropriate sliver reduction should be recommended.

5. Conclusions

1. Experimental study of the lab samples and cross-sections of trimmed parts from production showed that hairlike 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 is observed for wide variety of clearances between the shearing edges for both 0 and 15° 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.
2. Machining a small radius on the upper shearing edge prevents separation of slivers from top of the offal. Controlling the clearance between the shearing edges within several percents of the material thickness prevents formation of burrs and possible splits from trimmed surface in flanging and hemming operations.

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