Processing for Aluminum Auto Body Sheet

Understanding Key Differences in Working with Aluminum Versus Steel

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Stamped steel sheet metal has been the solution of choice for car bodies for more than one hundred years[1]. Automakers drove the development of steel auto body sheet (ABS) and created an entire industry to build the tools required to process and assemble stamped parts.

Interest in aluminum ABS arose precisely because it seemed a direct substitute to steel, simplifying the drive to lighter weight parts. But, as the industry soon discovered, aluminum ABS requires its own set of processing and tooling guidelines.

Part III of the 2022 Aluminum Formability Seminar (Automotive Body Sheet Formability and Stamping Webinar Replay) presented some fundamental guidelines that will be expanded upon here. This publication will not offer styling tips but focus on processing differences between aluminum and steel sheet. To illustrate, this paper will use the same door opening panel (DOP), since it incorporates all the issues faced by the major skin panels, and simply talk about aluminum and steel sheet when referring to the respective auto body sheets to help readability. But, before going any further, there are several general points that are worth remembering.

The first is that aluminum sheet, despite a similar yield strength to mild steels, behaves more like DP590 in terms of elastic behavior. Any springback related issue will be exaggerated and demand higher levels of compensation than steel skins, let it be in the draw die or the flange die.

The second is that there is nothing intrinsically alien in aluminum sheet, it is simply different than steel sheet. For example, there is no fundamental reason preventing the industry from achieving high craftsmanship levels by restriking a Class-1 mating radii after the draw die, like it is done with steel sheet.

The third one, edge stretch, is a more fundamental issue and is ignored at one's peril. Unfortunately for aluminum ABS, the edge stretch behavior is linked to the anisotropy ratio, or Langford coefficient, more simply known as the r-value. The first paper[2] in this series explored the implications of low r-value for the draw, this paper will now explore how it impacts edge stretching. As described in Part III of the 2022 Formability Seminar, the theoretical limit for edge stretching is the intersection of the uni-axial tension line and the Forming-Limit-Curve (Figure 1).

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[1] The 1915 Dodge Model 30 had the first mass-produced body made entirely with stamped and welded steel sheet parts.

[2] "Aluminum Galling and Lubrication for Automotive Applications" prepared for the Aluminum Association by Laurent Chappuis

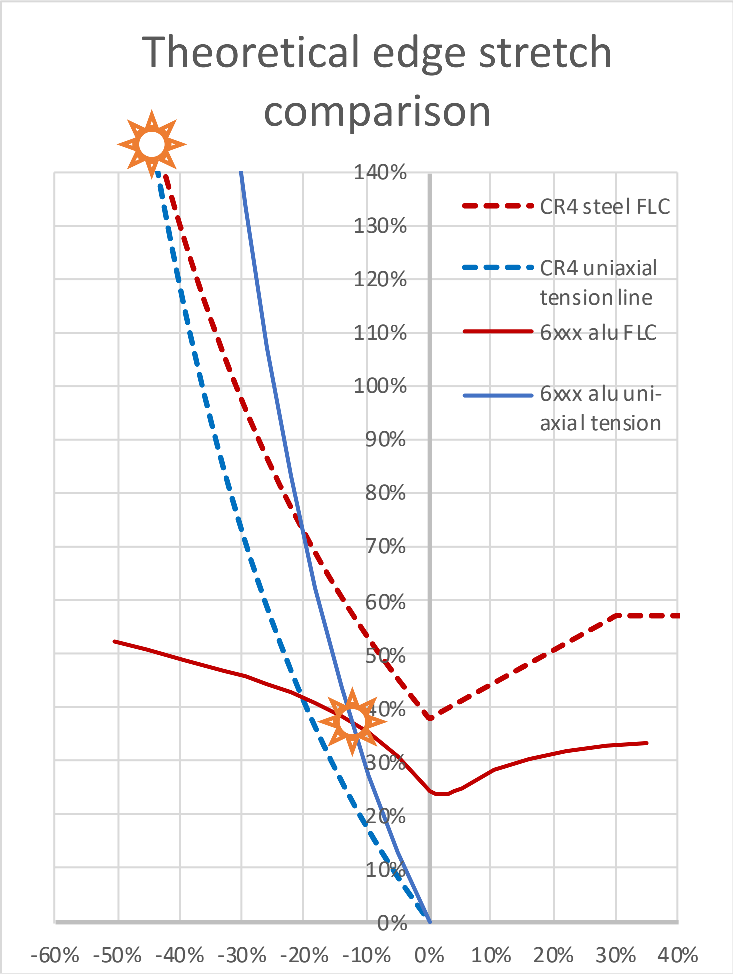

Figure 1: Comparing theoretical edge stretching potential

As shown above in Figure 1, the limit for aluminum is about four times lower than for the mild steels used in DOPs. The reliable limit achieved in production is considerably lower, driven down further by a greater sensitivity to any local defect trim edge created during the cutting. As shown in the example below, such a reduction in edge stretching has serious implications in processing.

Draw Die

The basic concept will include binders on floating pads in the openings, timed to close at the same time as the main binder.

1. No need to finish the form in the draw die, production can reform/restrike in later operations, if the required guidelines are followed.
2. Springback considerations draw the header and roof line flanges partially home, to minimize the length of line change when bringing them to their final position.
3. For craftsmanship, plus all Class-1 radii within at least 97% of their length of line of their final geometry.

4. Unlike for a steel DOP, the edge stretching restrictions force the industry to plan in bringing most of the metal from the binder (outside the part) rather than from the hole expansion on the inside.

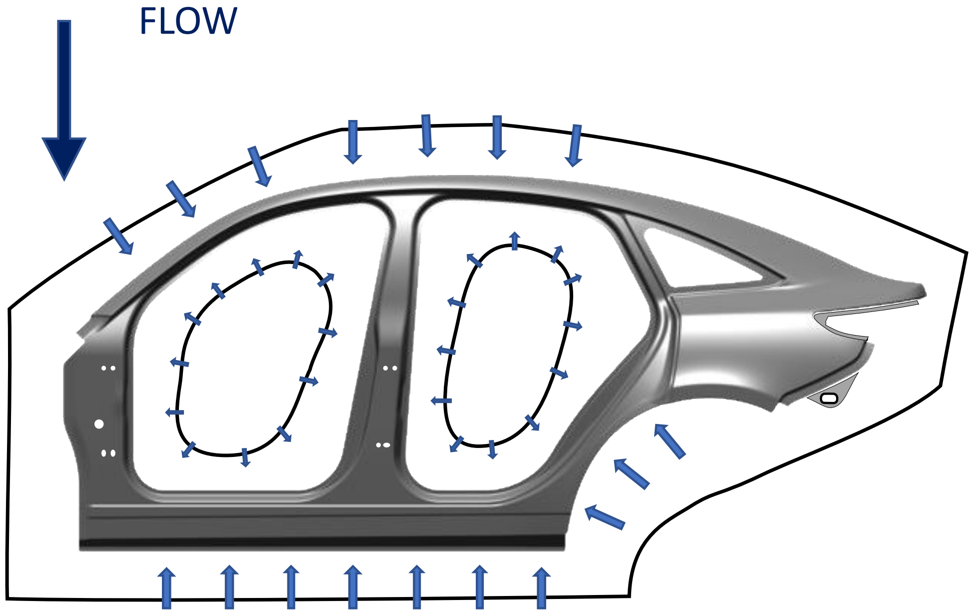

Figure 2: Material flow concept for a DOP draw die

This paper illustrates the reason easily. Assuming a 60% edge stretch limit for steel CR4, a 400mm hole can safely expand to: 400+60%x400 = 640mm. That means bringing 120mm of metal from inside the door opening into each wall. For an aluminum DOP with a 15% limit on expansion, the same 400mm hole can only stretch to 400+15%*400, or 460mm, meaning that the hole expansion can only supply 30mm to each wall. Draw beads will be necessary to control the metal movement in the opening.

For the same reason, practitioners must minimize edge stretching into the wheelhouse area.

5. No trimming, piercing or lancing in the draw

Although steel CR4 and the 6xxx aluminum ABS used for a DOP have similar yield strengths, the aluminum will have three times the springback, so that die compensation is necessary. The industry must take advantage of modern computer simulation, understanding that the best results will occur in an environment where the final drawn shell matches the simulation for blank size, location on the die and inflow.

Trim Dies

(And blank dies too)

First, the good news:

1. Same 10% metal thickness clearance as steel

Everything else will be metal specific. To illustrate the differences between the two metals, it is important to understand how trimming takes place.

Figure 3 shows a schematic section of a trim die as the upper steel is about to initiate the cut:

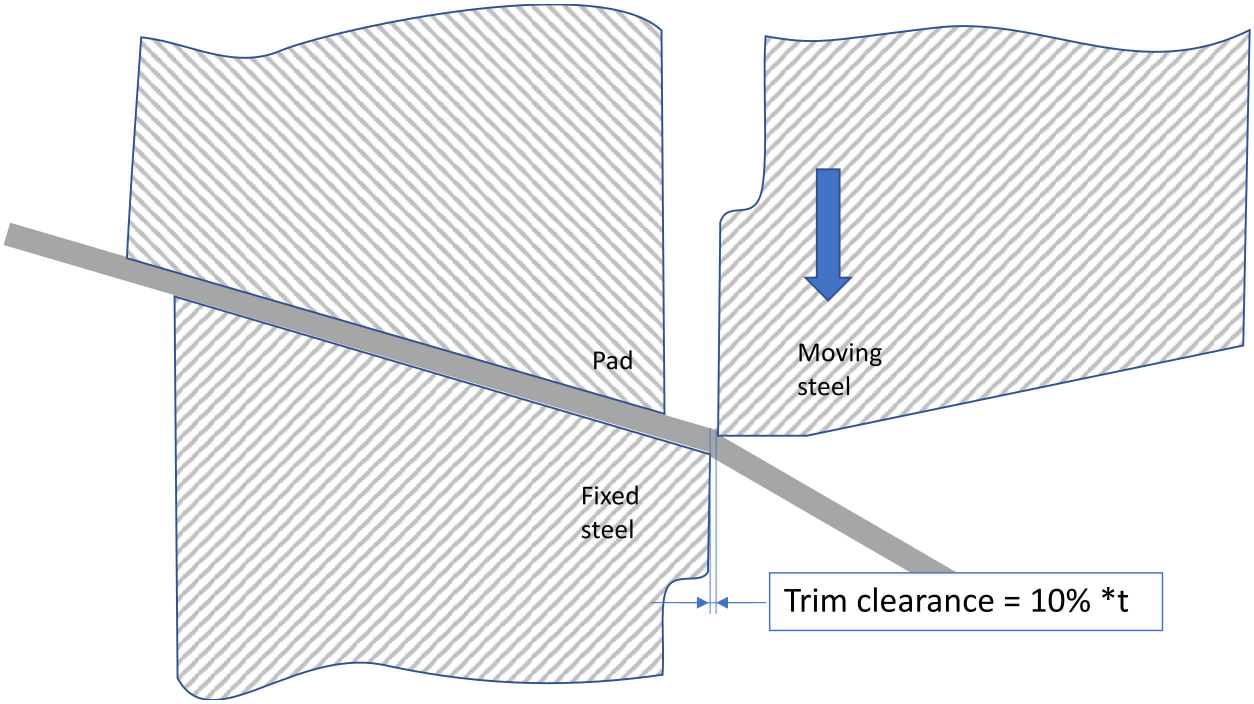

Figure 3: Trim die at cut initiation

Steel and aluminum ABS are both ductile materials, and it takes work to initiate the fracture that eventually result in the desired cut. To make that happen, the sheet is held onto the lower steel by a pad. When the moving steel contacts the sheet, two things happen: First, the whole sheet is put into compression, which will quickly exceed the elastic limit. As the plastic deformation progresses, it leaves the telltale rounded top surface of the trimmed edge. If the clearance is too large, or the lower trim steel edge is dull, there can even be a through thickness extrusion of the sheet, leaving a burr (Figure 4).

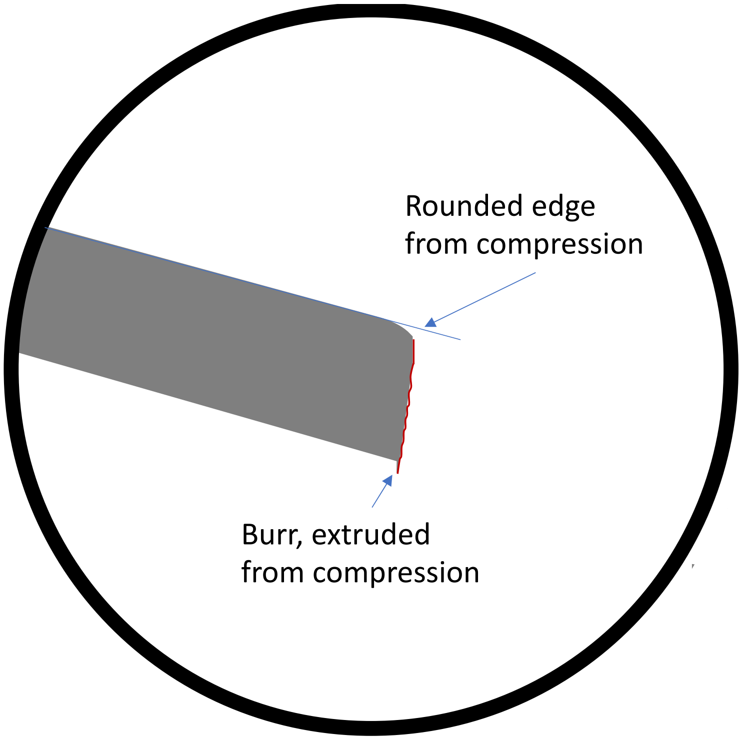

Figure 4: Telltale signs of the compression efforts

The second consequence is that, because of the trim clearance, the movement of the upper steel causes a rotation of the sheet, with the edge of the lower steel as its pivot point. This rotation adds compression on the lower surface and tension on the top surface. This is where the aluminum ABS' lower elastic modulus not only works against it, but the situation is aggravated by the usual 50% increase in sheet thickness. With a 3X lower elastic modulus, it takes 3X the compression distance to reach a similar yield point. This magnifies the rotation, further increasing the difference in surfaces stresses. If the two steel edges were equally sharp, a first crack initiation would start on the upper surface, followed by a second on the lower. In a perfect world, the two cracks would meet, and the trim would be neatly complete. In practice, the two events happen randomly along the trim edge, and the cracks never meet. Because of the compression, the metal between the cracks "explodes" as the compression is released, creating slivers.

The elastic modulus being a fundamental property, the effects can only be mitigated by:

2. Avoiding trimming "on air," meaning no conventional scrap cutters. Use chunk trimming or bypass-free scrap cutters instead.
3. Utilizing "sharp lower/ dull upper" strategy using differentiated tool steel alloys to foster a single crack initiation (using a slightly weaker material on the moving tool will quickly achieve the desired sharpness difference).
4. Sequencing the chunk trimming to minimize rotation, saving the corner pieces for the second trim. (Figure 5)

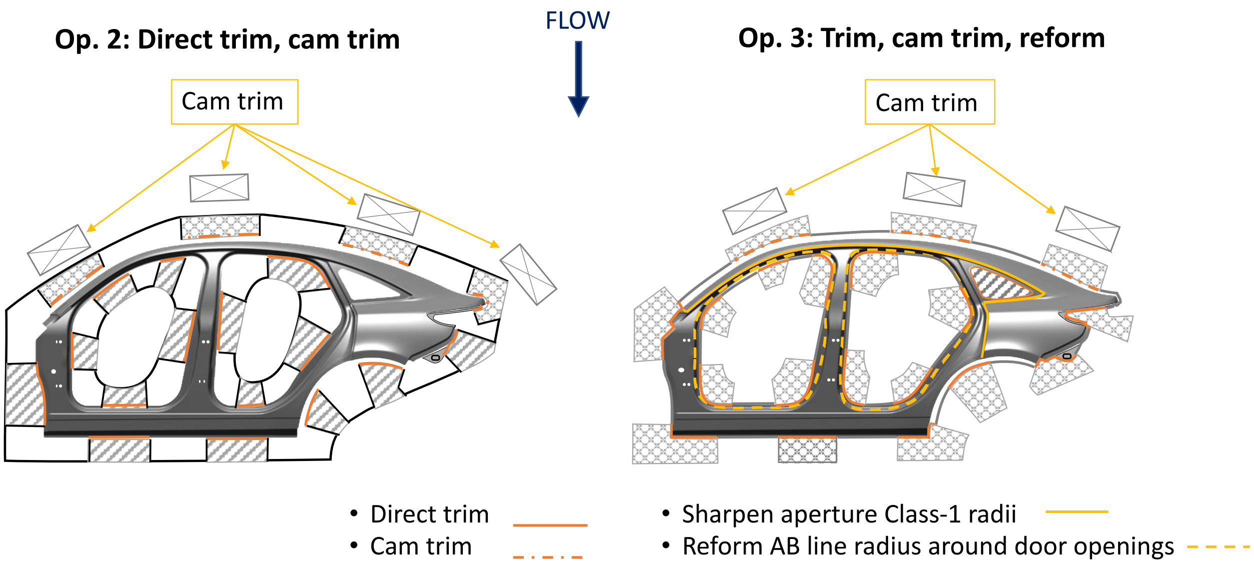

Figure 5: “Chunking” strategy for a DOP, in Ops.2 & 3

The increase elastic behavior has other subtle geometrical implications which aggravates the contact between the moving steel and the sheet, requiring some further mitigation efforts:

5. Diamond-Like-Carbon (DLC) coating on cutting face of upper to minimize the rubbing forces
6. Limit the entry to (5-6) x (metal thickness)

However, entry is necessary to help shed the scrap, so it should be an intrinsic part of the shear strategy. For large parts, shear provides the scissor effect necessary to manage the impact loads. Therefore:

7. Keep shear angle low, ~1°, corresponding to 6mm entry over 300mm trim length.

Steel scrap pieces weigh twice as much as their aluminum counterparts, and in high-speed processes, their higher density helps them fall faster than aluminum ones. Production statistics show that scrap shedding can easily be the number one downtime issue in high-speed aluminum processes. So:

8. Maximize the size of the scrap pieces
9. Include strategies to help shedding

From a tool design point of view, it is important to place joint lines strategically, away from high compression or stretch edges. Always offset joint lines between the upper of the lower part of the tool.

Flange Dies

Conceptually, there are few differences between flanging an aluminum skin panel compared to a steel one. All the difficulties are related to the difference in elastic modulus, and therefore springback. Except for the tonnage, flanging an aluminum skin is akin to flanging a DP590 part, a situation unfamiliar to process engineers. Finally, because flanging takes place in three-dimensional space, it has the potential to markedly affect the final geometry of the part.

Flanging can be categorized according to its effect on the edge of the flange.

- Bending: no change in the length of the flange edge.
- Compression flange: flanging around a curve, where the original length of line is longer than the final one (also, $R_o > R_f$)
- Stretch flange: flanging around a curve, where the original length of line is shorter than the final one (also, $R_o < R_f$)

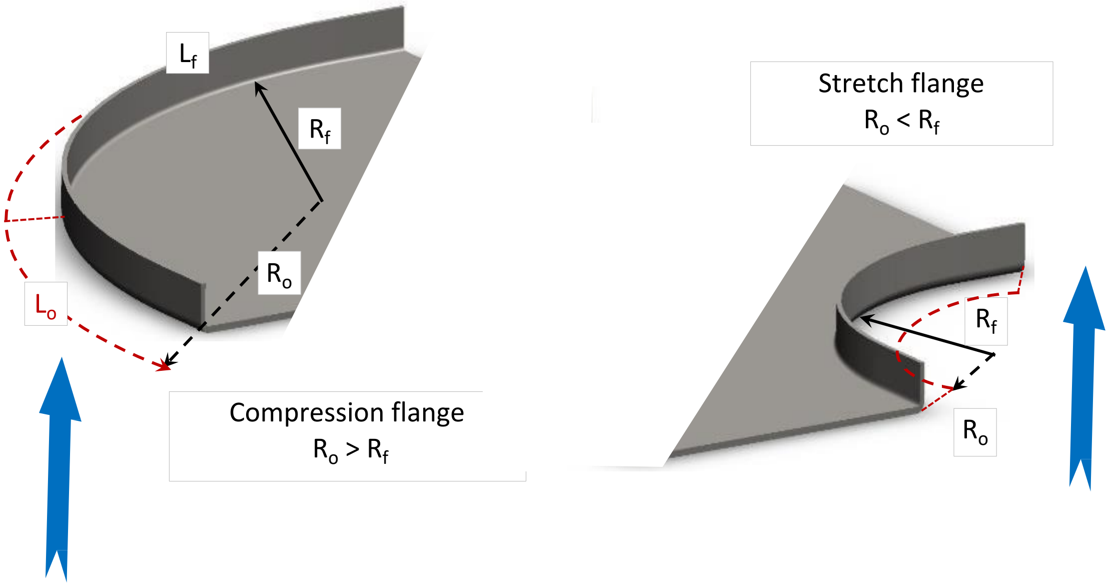

Figure 6: Compression and stretch flanges

From a process and tool design point of view, the simplest case is bending—the only concern is to account for a sufficient compensation for the springback angle.

However, compression and stretch flanges are complex three-dimensional problems, resulting from the combination of angle springback and the effect of the elastic recovery on the flange and the whole part. To simplify the explanations, the assumption that flanging occurs from an initially flat surface, as shown in Figure 6.

For a compression flange out of the tool, the hoop length of the flange will grow because of the elastic recovery. In such an unconstrained condition, this will cause the part to bow; in the simple example, the free part would no longer be flat, and the wall angle would have opened. If the surface were constrained back to flat, the flange would simply open some more. Short of compensating the flange post, there is nothing to be done to the flange steel to correct the issue, besides keeping the flange as short as possible.

The situation for a stretch flange is similar, but in this case, the hoop length of the flange will shrink under the elastic recovery, bowing the piece in the opposite direction. Constraining the piece back to its original flat condition will cause the flange angle to close, counteracting the opening of the flange angle. For large stretch flanges, like the glass line of a hood or a trunk lid, or the wheel well areas of fenders or DOPs, "timing" of the flange will help the part lie flat on the mating post during assembly. "Timing" the flange is arranging the geometry of the flanging steel to enter progressively (Figure 7). Sufficient timing will stretch the edge of the flange, and if done correctly, will eliminate the fit issue during assembly.

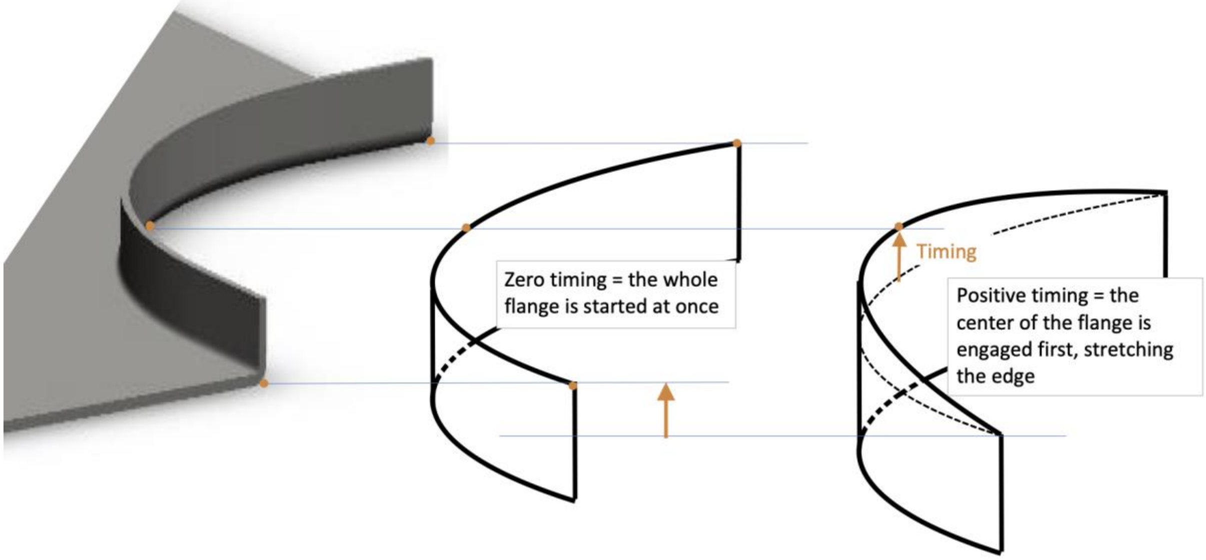

Figure 7: Timing of a stretch flange

To succeed, the timed flange tool needs to plastically stretch the edge of the flange. Aluminum is 3X more elastic than steel, and given their similar yield strength, timing the flange tool of an aluminum part is 3X larger.

This has an important implication for the tool designer, who will have to provide for the increased tool travel. For example, it is not unusual for the glass line of a modern hood to be timed by as much as 60mm.

From a tool design point of view, it is important to place joint lines strategically, away from high compression or stretch edges. Furthermore, joint lines should always be offset between the upper and the lower part of the tool.

Summary

Processing an aluminum skin requires the engineer to remember the following simple rules:

1) Aluminum ABS is not alien, just different, craftsmanship is possible by restriking Class-1 mating radii.
2) The insidious edge stretch limitations and their effect on hole expansion.
3) Keep hem flanges short.
4) Trim dies require special planning: the 9 recommendations listed are necessary to minimize slivers.
5) Flange die timing for glass-lines stretch flanges is 3X larger than for steel
6) Overall springback is similar to DP590.
7) Die design to pay special attention to the position of joint lines in trim and flange dies.

Acknowledgments:

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