Sheet Hydroforming of Aluminium Body Panels

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Abstract

This paper discusses the application of sheet hydroforming technology to the forming of deep draw aluminum automotive body panels. Over the last few years there has been a shift in the automotive industry to focus on lightweight bodies to minimize fuel consumption. Currently, the amount of aluminum in vehicle architectures is somewhat limited due to cost and also the inability to incorporate common body panel design to aluminum sheet due to lower formability. Typical aluminum sheet has approximately about 30~40% of the formability of comparative steel grades. Automotive designers have been hampered by this fact and have not been able to successfully introduce aluminum sheet for wide range of panels. To meet these new challenges in the industry, Amino has had to adjust and re-focus its sheet hydroforming technology. Sheet hydroforming has a formability advantage over many types of forming methods. This paper will discuss those advantages and show some successful applications to the automotive industry.

Introduction

The automotive industry is in a state of upheaval. The general public and world governments are pressuring carmakers to improve vehicle gas mileage (CAFE requirements) to minimize not only their carbon footprint but their overall reliance on fossil fuels. Automotive companies are looking at various new vehicle platforms to minimize the gas consumption via hybrid, electric, fuel cell and others. Each OEM is developing technology for these new requirements, but the one key factor to all is lighter vehicle weight. Whether for these new platforms or for existing platforms lighter weight means better fuel economy. Better design and lighter materials are the methods to achieve lighter weight. However, with lighter material such as aluminum conventional forming methods sometimes cannot be used. Especially for stamped panels such as Hoods, Doors, Fenders and Frames, the percentage elongation of material when compared to steel is 30~40% less. This means that current vehicle designs cannot be formed with conventional manufacturing methods. As can be shown in Figure 1 as the degree of difficulty of the panel increases there is less aluminum content in the vehicle. These are prime untapped parts on vehicles to convert to lighter weight materials.

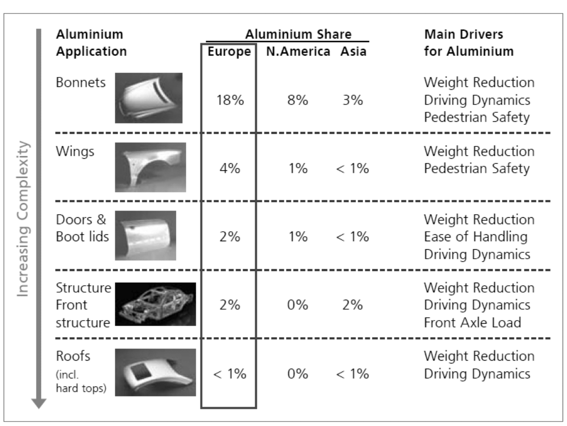

Figure 1: Aluminum Share versus Part Complexity

Sheet Hydroforming

The Amino sheet hydroforming method is shown in Figure 2. A sheet metal part is formed by water pressure generated by the punch drawing the sheet into a pressurized water chamber. One merit of using sheet hydroforming is higher formability. Higher formability, draw ratio or forming limit is due to water pressure holding material to punch through the forming process, protecting the panel from local thinning at critical areas.

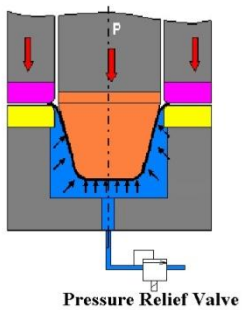

Figure 2: Sheet Hydroforming

A typical sheet hydroform tool set is shown in Figure 3. The upper punch is the male side and has the shape of the part machined into it. The punch is surrounded by the upper binder or blankholder that provides holding force to the blank. The lower die or water chamber acts as the lower binder surface that holds the initial blank and the pressure chamber to provide hydraulic counter pressure to the water. The punch / blankholder combination is attached to the press slide and separate hydraulic cylinders provide the force to the blankholder. This blankholder force is controlled through hydraulic circuit and system PLC, programmable logic control. The water is pumped into the chamber below the die. Water flowing out of the die is controlled through water relief valve. This pressure is also monitored by system PLC.

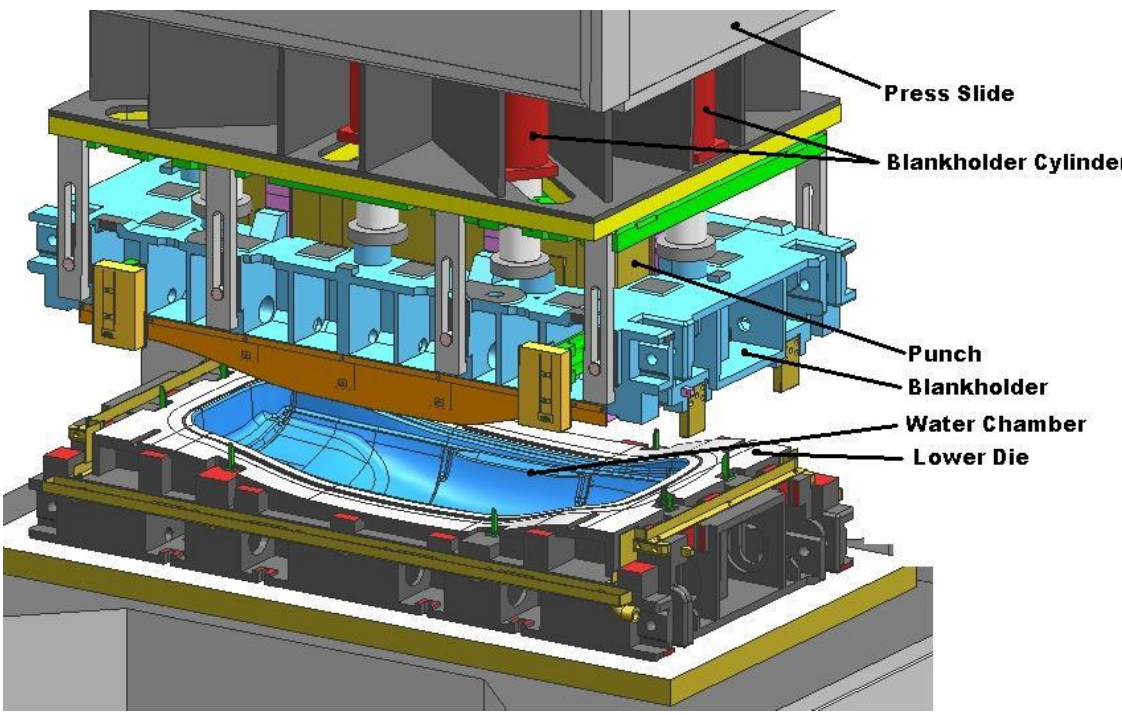

Figure 3: Typical Sheet Hydroforming Tool Set

The process begins by the robot setting a blank on the lower binder surface of the die. Water will already have been pumped into the water chamber. The slide descends pushing the punch and blankholder combination. The blankholder cylinders engage providing blank holding force to the material controlling the draw-in and stretch of the part. The slide will continue to descend pushing the blank into the water chamber. Due to the displacement of water volume water is compressed and pressure begins to build. The pressure pushes the blank to the punch as can be seen in Figure 4. The slide and punch will continue descend in a controlled manner to bottom of stroke. The slide will return to home position pulling the punch, blankholder and newly formed draw shell with it as shown in Figure 5. Water will be pumped back into the water chamber and a robot will take the drawn shell and transfer it to the next operation. The cycle will then continue.

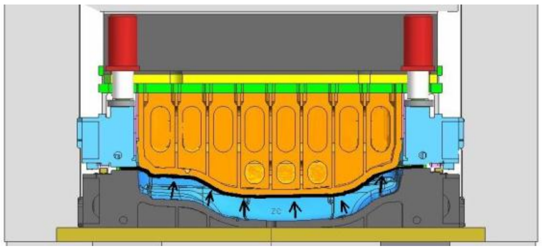

Figure 4: Water Pressurization

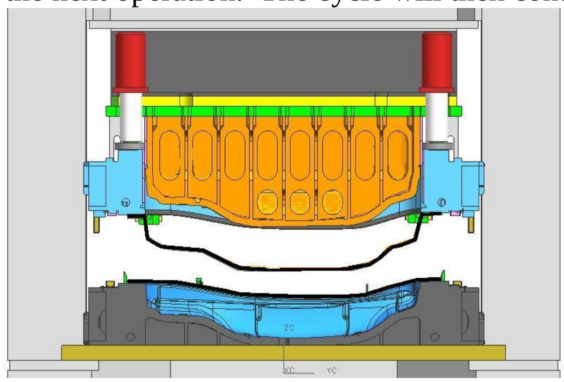

Figure 5: Finished Panel

Many parts have been formed by sheet hydroforming process over the years. Typical applications are deep drawn class A parts. Typical examples are shown below. Figure 6 shows are a front face for Japanese kit car from Mitsuoka. The material is mild steel at 0.8mm. Figure 7 is a decklid outer for a Volvo S80. The license plate pocket is actually an undercut area and the material is mild steel at 0.8mm. Figure 8 is a boxside outer for a dually type heavy duty truck for General Motors that is currently in production. The material is a deep draw quality steel at 1.1mm. Figure 9 shows a front fascia for a Ford F150 Raptor truck that is currently in production. The material is deep draw quality steel at 1.6mm.

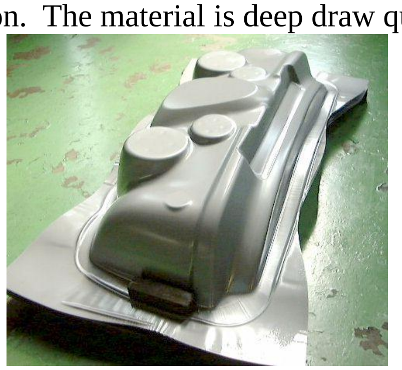

Figure 6: Mitsuoka Front Face

Figure 7: Volvo Decklid

Figure 8: Dually Boxside Outer

Figure 9: Raptor Front Fascia

Sheet Hydroforming of Aluminum

One of the more exciting new developments of sheet hydroforming is the application of the technology to the forming of aluminum. The deep draw capability as seen in the steel panels could be an advantage to forming aluminum which traditionally has 30~40% lower formability than steel. Basic initial research was shown in experiment by Nakamura in 1985, Figure 10, a sheet hydroformed aluminum cup can achieve a much greater depth of draw than a conventionally drawn one. Figure 11 shows the much higher draw ratio of sheet hydroformed aluminum when compared to the conventionally formed cup.

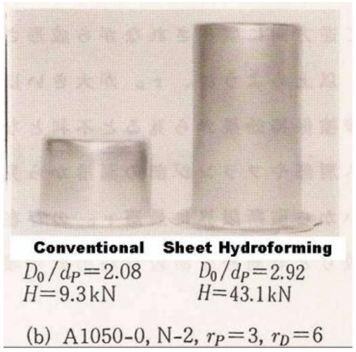

Figure 10: drawn cups

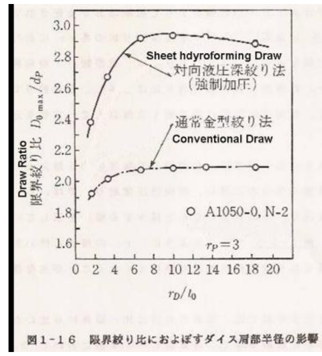

Figure 11: Draw Ratio

This experiment can now be shown by current forming simulation analysis. Using PAMSTAMP simulation software a study of a typical cup using A6111-T4 was undertaken comparing conventional stamping to sheet hydroforming. The conventional cup is shown in Figure 12 and is split at the punch radius at 80mm of depth. The sheet hydroformed cup is compared in Figure 13. As can be seen in the file the cup was drawn past 140mm of depth with still no fracture. This is almost a 50% increase in draw depth. Additionally if you notice the color map the thinning distribution is much more even across the entire part when compared to the stark band of high thinning at the punch radius of the conventional cup.

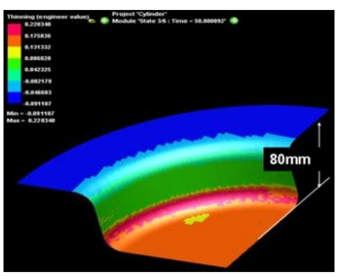

Figure 12: Conventional

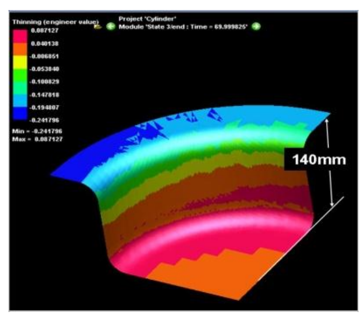

Figure 13: Sheet Hydro

As is shown in experiment and analysis high water pressure prevents localized material thinning at critical areas allowing a deeper draw. This basic principle can be adapted to benefit typical automotive panels as well.

Initial Research

To prove the basic research as noted above physical tests of panels were performed on existing tooling to understand the potential of converting steel panels to aluminum. Initially, simulation was performed to predict formability and potential issues as shown in Figure 14. Results from the simulation show no splitting but potential for loose metal on the top of the panel near the heat extractor pocket of the fender.

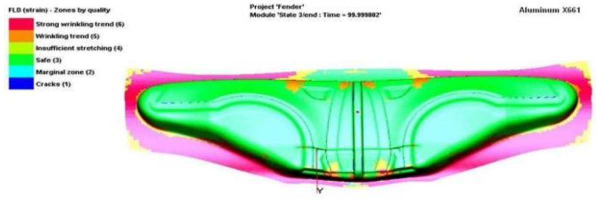

Figure 14: Fender Draw Simulation

The actual formed steel panel as shown in Figure 15 is a BH210, t0.7mm steel fender draw shell. By comparison using the same tool and adjusting water pressure, blank size and bead strength a panel of A6111-T4, t1.0mm panel could be successfully formed as shown in Figure 16.

The aluminum draw shell compared very well to the simulation model. Bead strength adjustment to minimize draw in eliminated any loose metal in the panel. No modifications to panel geometry were required.

Figure 15**:** Fender BH210

Figure 16**:** Fender, A6111-T4

Figure 17: Al. Fender

The draw shell was further processed to trim and flange the panel to the fender as shown in Figure 17. It was noted there is 3kg weight savings when compared to the steel panel. The panel was measured with CMM and compared with production steel panel. Results are shown in Figure 18

The dimensional results shown are surface points. The results show some spring back in specifically in the rocker and wheel arch area. This information could then be used to compensate a new tool if an aluminum fender were to go to production.

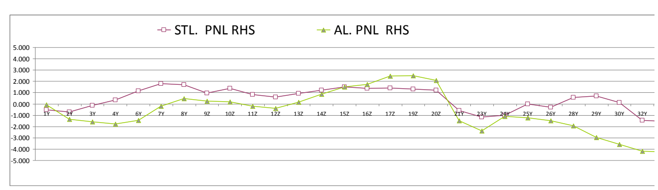

Figure 18: Dimensional Comparison Steel to Aluminum

Aluminum Hood Research

A Hood assembly, outer and inner panel were next chosen to test. Again, tools that made steel panels were utilized for the tryout. The steel panels were produced by sheet hydroforming and at the time of original development were considered too difficult to stamp conventionally. A test to see if these parts could be sheet hydroformed in aluminum was a good opportunity to test the boundaries of the technology.
Forming simulation software PAMSTAMP was again used to predict forming and validate the analysis software

for future application. Simulation analysis was first conducted on the original steel panel to validate the software to the formed panel and design. A validation was obtained and then aluminum, A6111-T4 model was then run to predict formability. The result is shown in Figure 19. From this model it can be seen that there would be splits in small radiuses of the panel in the headlamp and inner strengthening beads.

As the production tool was currently being used and could not be modified it was decided to build a new tool to the original design and validate the simulation against actual test results. Splits and other defects would be worked on in the tool and compared against the simulation. A spring back analysis was also done as shown in Figure 20 to compensate the tool prior to build.

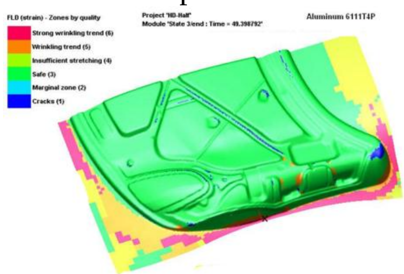

Figure 19: Hood Inner Formability Simulation

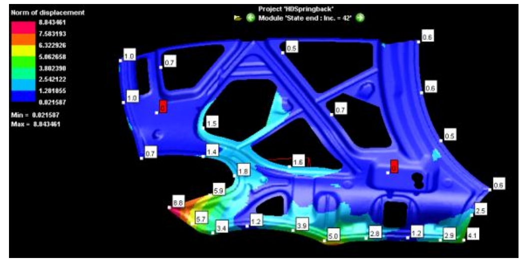

Figure 20: Springback Analysis

Based up the analysis a new die was constructed and actual tryout done. During tryout as per initial formability analysis some radius in the panel needed to be opened up to make a good part. These changes matched the simulation analysis well. The radius changes in our opinion would not affect the functionality of the part by any great amount. The aluminum hood inner is shown in Figure 21. A 5kg weigh savings was achieved in this panel.

Figure 21: A6111-T4, t0.8mm Hood Inner

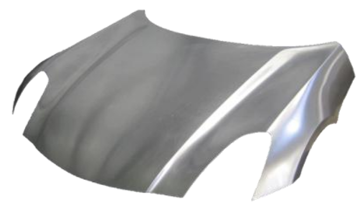

Figure 22: Hood Outer, A6111-T4, t1.0mm

The outer skin was then investigated. Tests on existing production tooling that makes steel panels were conducted with A6111-T4, t1.0mm. The finished panel is shown in Figure 22. The difficulty with this type of clamshell hood is minimize slip line surface defects across feature lines but still maintain good strain in the panel for maximum dent resistance. As this panel is deep draw, stretching the panel to improve strain results in panel splitting. However, using water pressure allows the protection of movement over the feature line yet allows a more even strain distribution. Draw shells were made with good surface quality. Panels were trimmed and flanged also in production tooling. Excellent jewel radius flanges were obtained especially in corners of front nose that are typically difficult to form. Circle grid tests show 4% minimum strain in the centre of the panel. This is actually higher than the production steel panel. A total weight savings of 6kg was obtained.

Aluminum Door Inner Research

Doors are also considered prime parts to convert from steel to aluminum. Although the outer skin is typically easily converted the inner is very difficult. The deep draw requirements with steep side walls and tight radiuses make a door inner almost impossible to form in aluminum.

A typical door inner model was chosen for test and as was the case in past tests initial formability simulation was undertaken to predict formability. The formability led us to consider forming the panel in two operations; a sheet hydroformed draw with a conventional restrike. A kirksite test tool was built and panels made. The material used was A5182-0 at 1.5mm thick. The two operation method worked very well with good quality panels made. The draw shell is shown in Figure 24. The finished panel is shown in Figure 25.

Figure 24: Door Inner Draw

Figure 25: Door Inner Finished

Aluminum Panel Production

The first aluminum production panels from sheet hydroforming process were taken in February of 2011. The vehicle is an all aluminum body and frame to maximize weight reduction to improve vehicle range for a hybrid vehicle. The hood outer, hood inner, door outers, body side outer and body side inner were chosen to form by sheet hydroforming technology. Initial forming simulation was done on all panels prior to tool design and build. Good results and correlation to the springback analysis were obtained. Material used for the panels is a mixture of A5182-0 for inners and A6022-T4 for outer panels. Many of the panels were deep draw complicated parts utilizing the sheet hydroforming capability to the maximum

Conclusion

We believe based upon the academic research, practical test and actual production application that sheet hydroforming is well suited to the forming of aluminum body panels. The increased formability of the process offers advantages to designers who are looking to lighten vehicle weight.

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