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Sheet Hydroforming and Other New Potential Forming Technologies

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Abstract. Sheet hydroforming technology has been developed and utilized for decades by Amino to mainly produce class A body panels for the automotive industry. Extra deep draw depth, more even material thickness distribution and better surface quality can be achieved through this technology. Several automotive manufacturers are using panels made with this technology for its high degree of formability and lower tooling cost. Other industries such as commercial truck and bus have also developed interest in sheet hydroformed panels in their vehicle architecture.
This paper presents efforts to improve the technology via simulation and new tooling techniques. Warm forming is shown to greatly improve the formability of high strength aluminum alloys. However, surface quality is always a concern which limits its utilization in class A panels.
In addition, a new potential forming technology, Electro-Hydraulic Forming which can combine available technologies mentioned above to produce more aggressively styled parts with good surface quality using high strength aluminum alloys.
Finally, this paper will look at current development of sheet hydroforming technology and look at some actual industrial applications including the instillation of a new press for low volume production and future R&D, some review of warm forming experiments recently completed and future developmental programs with warm forming and sheet hydroforming in the near future are discussed.

1. Introduction

Sheet Hydroforming is a process where water or fluid medium is used under pressure to form sheet metal. It is still widely used in various industries for low volume production. There are many types of sheet hydroforming being used. Rubber forming as shown in Figure 1 forms sheet metal into a rubber pad. Bladder forming uses a pressurized rubber bladder to press metal to a mold as shown in Figure 2. Active Hydro-Mechanical forming as shown in Figure 3, uses water as a medium directly on the sheet metal but is actively pressurized via an intensifier. Finally, Hydraulic Counter Pressure forming, as shown in Figure 4, or the Fluid Forming Process, FFP, uses passive water pressure.

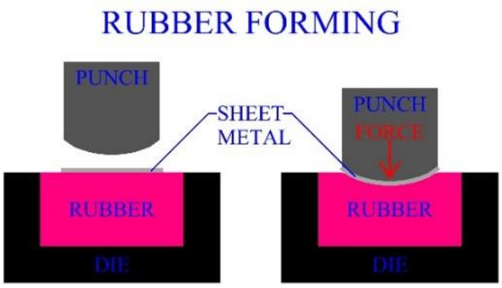

Figure 1. Rubber forming.

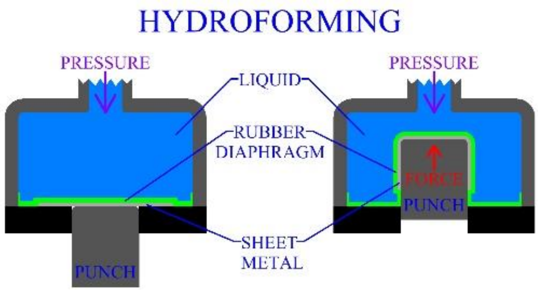

Figure 2. Bladder forming.

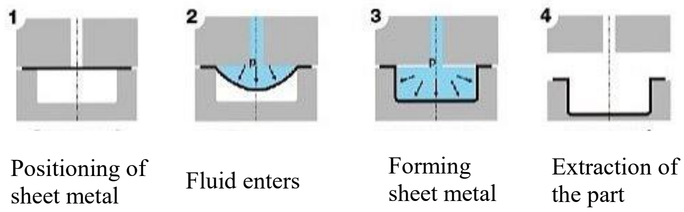

Figure 3. Hydro-mechanical forming.

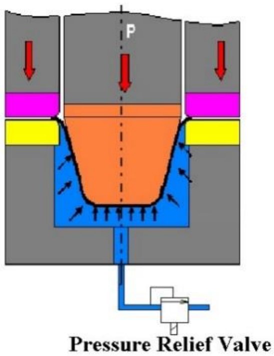

Figure 4. Fluid forming [1].

2. Fluid forming process

This paper will discuss Hydraulic Counter Pressure Forming or Amino's Fluid Forming Process, FFP.

2.1. FFP Tool

A Fluid Forming tool as shown in Figure 5 is a three-piece die. The blankholder is hydraulically controlled. The setup can work in either a double acting press or single acting fitted with hydraulic cylinders that add blankholder force. In this case the diagram shows a single acting press with blank holder cylinders embedded into the slide.

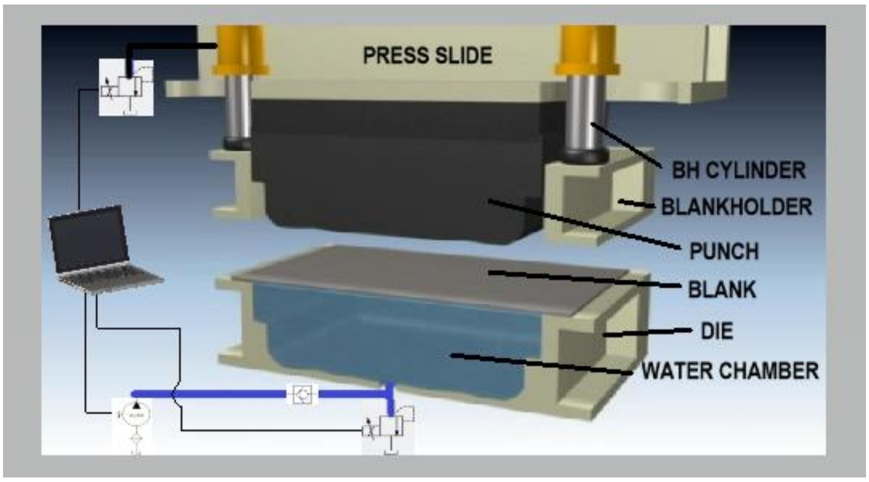

Figure 5. Typical FFP tool set [1].

The tool set consists of a punch which is the master. The lower die is both the water chamber and holder of the blank or sheet material. The blankholder provides holding force to the blank to control material flow into the water chamber. The blankholder cylinders that control the force to the blankholder are computer controlled to adjust force through the forming of the part. The water discharges during forming through a special pressure relief valve to the holding tank. This valve is computer controlled and is designed to control the water pressure in the die during the forming process. The water pressure follows a set recipe for each part or die that is in production. Once the cycle is complete the slide will pull the upper tool set up to original position and water will be pumped back into the water chamber.

2.2. FFP process

The forming process as shown in Figure 6 starts with sheet metal blank set on the lower die by robot. The slide descends and the blankholder holds the blank to the die surface via the hydraulic cylinders. As the slide continues to descend the punch pushes the blank into the water chamber building pressure and securing the sheet firmly to the punch until it reaches bottom. Low water pressure is used to minimize required press force to improve cycle time. However, a lower die is required to calibrate small radiuses that low pressure cannot form. After forming the part is pulled out the cavity by the action of the slide returning to initial position.

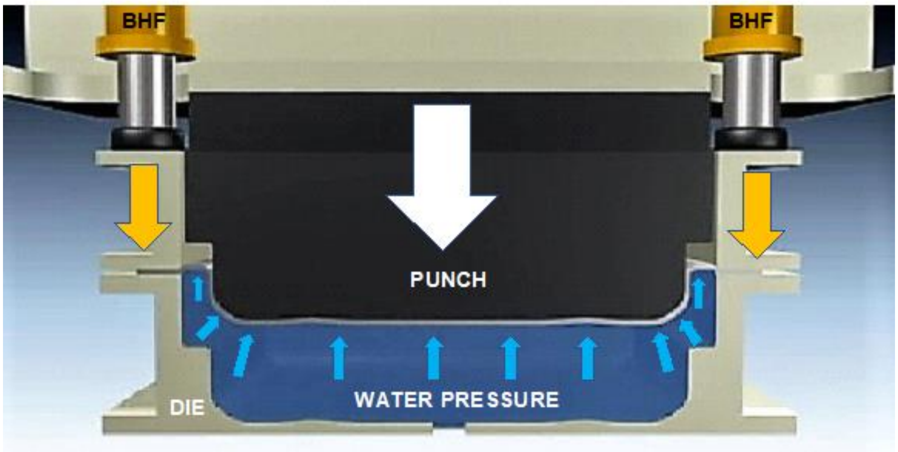

Figure 6. Fluid forming process.

Fluid Forming is a passive pressurization method [2]. The sheet metal clamped to the die and the outflow blocked by the relief valve implies a pressure vessel initially at zero pressure. As the punch pushes the sheet metal into the water chamber it compresses the water until pressure builds. The outflow of water through the pressure relief valve controls the pressure within the water chamber. This back pressure forms the sheet metal to the punch.

2.3. FFP formability

The main advantage of FFP lies in drawing parts deeper when compared to conventional forming. FFP overcomes conventional stamping forming limitations. This has been proven experimentally on many occasions such as experiments by Nakamura in 1985 [3] on different materials like steel and aluminum as shown in Figure 7. As can be seen experimental cups in steel and aluminum show large increases in depth of draw when comparing sheet hydroforming to conventional stamping.

The normal forming limitation of conventional deep drawing is localized thinning at the punch shoulder radius. However, water pressure pushes the sheet against the walls of the punch during the forming process. The punch radius is fully supported and an increase in friction along the wall ensures uniform thinning along the length of the wall [1].

It can also be represented by the differences in draw ratio compared to conventional forming. Draw ratio is a function of initial blank size to final part size. A comparison of sheet hydroforming and conventional stamping draw ratio to punch radius size is plotted below, as shown in Figure 8.

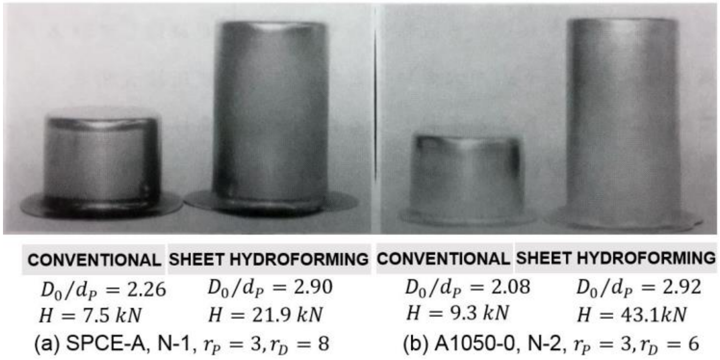

Figure 7. Deep draw cups [3].

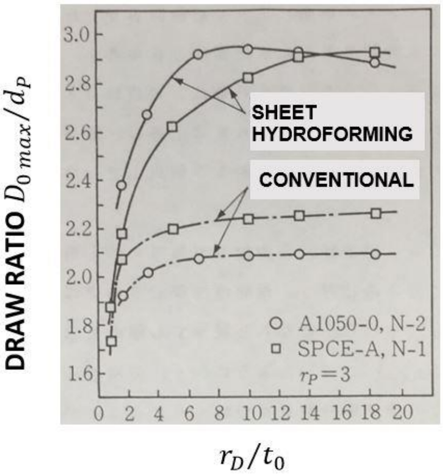

Figure 8. Draw ratio[3].

The two processes are compared using numerical simulation, PAMSTAMP software, considering an aluminum, A6111-T4 alloy blank. The conventional cup formed is as shown in Figure 9 is predicted to split at the punch radius at 80mm of depth. The sheet hydroformed cup, as shown Figure 10, did not fracture until 140mm of depth almost a 50% increase in draw depth. Additionally, the thinning distribution is much more even across the entire part when compared to the severe red band of high thinning at the punch radius of the conventional cup.

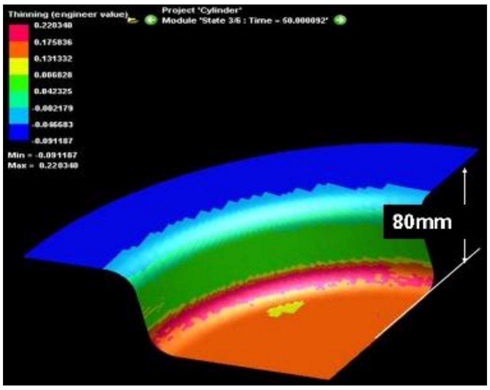

Figure 9. Conventional[4].

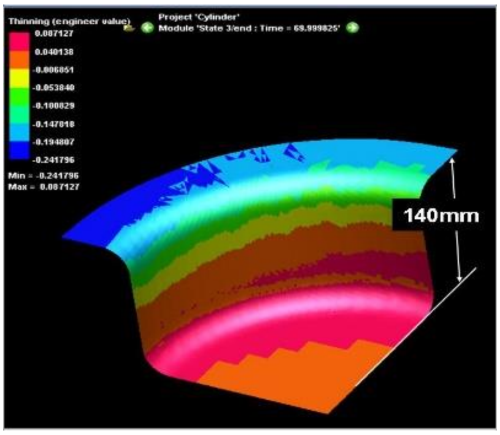

Figure 10. Sheet hydro[4].

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.

3. Sheet Hydroforming Applications

FFP and sheet hydroforming have been used in industry over many years. Aerospace, general purpose, lighting, appliance, automotive and heavy truck and bus are all typical industries that have used this process. Shown below are examples of deep drawn components from various industries.

3.1. FFP applications
Figure 11 shows a stainless-steel sink that has been drawn in one operation compared to four conventional operations. Figure 12 shows a Jet engine lip skin that is formed in one operation. Figure 13 shows a lamp case that would normally take multiple operations to form and Figure 14 shows stainless steel range top that exhibits better quality and higher strain to prevent material popping under high heat.

Figure 11. Sink, SUS304, t1.5 mm[5].

Figure 12. Jet engine lip skin, A2219-0, t1.6mm[5].

Figure 13. Reflector, A1080-0, t1.2mm[5].

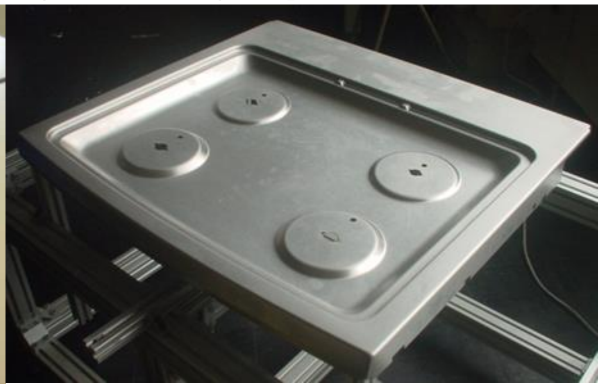

Figure 14. Range top, SUS304, t0.7 mm[5].

3.2. Aluminum fender
Aluminum fenders are generally difficult to form and process. The fender as shown in Figure 15 is for a high-performance version of a mainstream sports car. Sheet Hydroforming is used for this panel for both low tooling cost and higher degree of formability. The depth of draw was more than mainstream panel and the heat extractor pocket with sharp feature lines and pointed nose drove the panel to be formed with sheet hydoroforming.

3.3. Liftgate
An example of higher degree of formability is a liftgate for a North American Premium Vehicle as shown in Figure 16. The panel is a deep draw wrap-around design with tight features in the license plate, lamp can and window opening. The lampcan is a separate part welded to the main panel. Generally, this would be a two piece panel that is welded together but styling called for an uninterrupted patch around the lamp. With conventional stamping a one-piece design would cause heavy wrinkling and splitting. However, water pressure is used to eliminate loose material around the form of the panel. This project was a manufacturing finalist for an Automotive News PACE award in 2015.

Figure 15. Fender, A6022-T4, t1.0mm.

Figure 16. Liftgate, CR4, t0.6mm..

3.4. Front bumper

An off-road version of a typical North American pickup truck bumper is also being sheet hydroformed. The bumper is a three-piece assembly. All three parts are formed in one sheet hydroform draw to improve quality and minimize tooling and part cost, as shown in Figure 17. Styling was an important factor in using sheet hydroforming as conventional stamping could not form the tight radiuses and pockets.

Figure 17. Front bumper, EDDQ, t1.86mm.

3.5. Aluminum door outer and inner

Aluminum body panels are extremely difficult to form with conventional stamping. Figure 18 and 19 show aluminum door panels for a low volume super car. Sheet hydroforming is used to form these panels due to lower tooling cost and its higher degree of formability.

Figure 18. Door outer, A6022-T4, t1.2mm.

Figure 19. Door inner, A6022-T4, t1.2mm.

The door skin has a very narrow door handle opening with a slight depression at the back of the handle. This would typically cause splits and surface imperfections around the door handle but water pressure helps to form the depression and protect the surface quality around the door handle pocket. The rear feature line of the panel is also extremely sharp and needs hydroforming to form properly. The door inner is a deep draw panel with multiple layers that cannot be formed conventionally. Laser trimming is utilized to finish the panels to reduce tool cost.

4. Research and development projects

Further research and development work is underway with sheet hydroforming or using water forming with other processes. This work has been instrumental in improving and enhancing the technology.

4.1. Electro-Hydraulic forming

Electro-hydraulic forming EHF is a process where electrodes are placed in in a water chamber that acts as one side of a die. The Electrodes discharge high voltage which creates a high intensity shock wave that propagates through the water and pushes the sheet metal into the die as shown in Figure 20. Electrodes in the water can allow multiple discharges in the tool during forming.

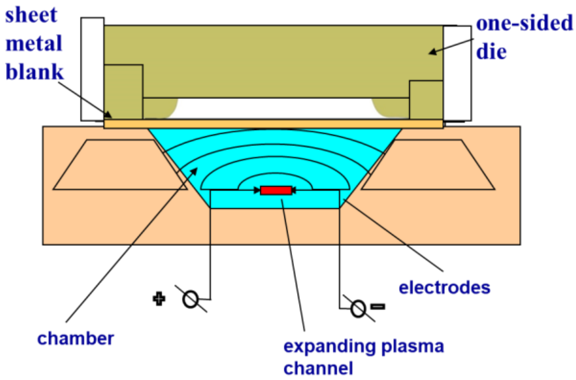

Figure 20. Schematic diagram of the EHF die set.

Figure 21 shows the electro-hydraulic die forming (EHDF) specimen formed into the 38° V-shaped die using a 13 kV pulse[6]. The strains in the neck and maximum safe strain regions were carefully measured in all the V-shaped specimens and are plotted with the quasi-static (QS) FLC of the DP600 steel sheets in Figure 22. More than 120% formability increase in the plane strain state was achieved locally near the top edge of the specimen. It was found that this significant enhancement in formability in EHDF are mostly attributed to the high-velocity impact against the die wall and the consequent high strain rate.

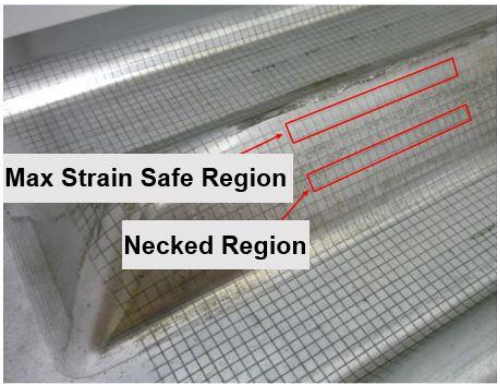

Figure 21. Necked and maximum safe strain regions of the DP600 EHDF specimen [6].

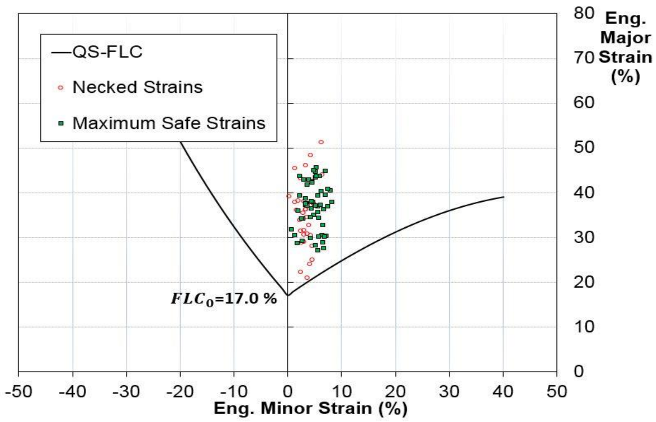

Figure 22. Engineering strains measured in necked grids and in safe grids in DP600 EHDF specimen formed into the 38° V-shaped die, and compared to the QS-FLC [6].

4.2. Warm forming of aluminum

At higher temperature, aluminum is more formable. Warm forming tests to build some knowledge around the technology. Figure 23 shows the schematic of a tool that has heating elements imbedded into it and coolant in the punch. It was determined that the blank and tool surfaces would be heated to high temperature but the punch cooled to room temperature to achieve the best results.

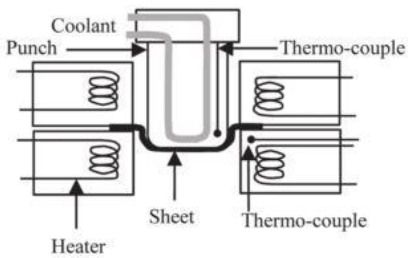

Figure 23. Test cups AA5182-0.

A tool was designed and simulation performed at various temperatures to determine the best results. The simulation showed that at 225°C the best results could be achieved as shown in Figure 24. Actual tests performed are shown in Figure 25 which provides a comparison of warm forming of A5182-0(left) to conventional deep drawing (right). A limit draw ratio of 2.35 was achieved for the warm forming sample. Better results are possible however stroke of the press was a limiting factor. Further tests will be conducted on large scale parts in the near future.

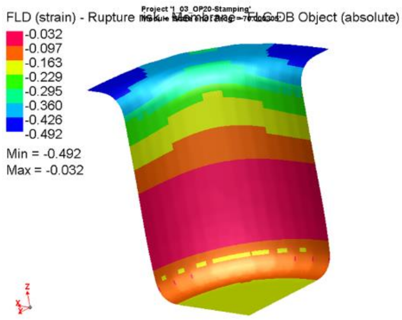

Figure 24. FLD by rupture.

Figure 25. Test cups AA5182-0.

5. New sheet hydroform press

To assist in these research projects a new sheet hydroform press has been installed at ANAC in 2017. The press has been tied in with another mechanical press to have a small automatic tandem line for small lot production, prototyping and research and development. Large scale tests and research is planned in 2018 around warm forming and other.

6. Conclusion

Sheet hydroforming continues to be a viable alternative method to conventional stamping when higher degrees of formability are required, especially for lower volume production applications in deep draw Class A outer panels. This forming process is attractive to premium auto manufacturers due to its flexible styling, dimensional stability and better surface quality under the circumstance of lower tooling investment and fewer forming operations. Further research and development into the process is being undertaken to improve its formability advantage and improve productivity.

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Electro-hydraulic forming and warm forming technologies are promising to push the sheet metal formability into the next level. In the case of electro-hydraulic V-shaped die forming, more than 120% formability improvement was achieved in local areas. This dramatic increase in formability is beneficial to make aggressive parts with deep pockets and sharp corners. Warm forming is still under investigation stage at Amino but the above 17.5% increase of formability was observed in terms of Limit draw ratio compared to the cold cup drawing. As concluded from current experimental tests, cooling effects of punch is important to make deep cup drawing successful. Right temperature distribution over the cup is critical to suppress the splits at the side wall of the cup. High temperature at the flange area of the part can promote the material flow over the die cavity and relatively lower temperature at the side wall can strengthen the material and impede the splits to occur.

References

[1] Maki T 2003 Current status of fluid forming in the automotive industry *Hyfroforming of Tubes, Extrusions and Sheet Metal* (Stuttgart, Germany)

[2] Maki T 2005 Sheet hyfroforming of Automotive Body Panels *Hydroforming of Tubes, Extrusions and Sheet Metal* (Stuttgart, Germany)

[3] Nakamura K 1985 *Study of Sheet Metal Hydraulic Counter Pressure Forming* (Chiba University)

[4] Maki T 2012 Sheet hyfroforming of aluminum body panels *Hyfroforming of Tubes, Extrusions and Sheet Metal* (Stuttgart, Germany)

[5] Amino H, Makita K and Maki T 2000 Sheet fluid forming and sheet dieless NC forming *New Developments In Sheet Metal Forming* (Stuttgart, Germany, IFU)

[6] Cheng J, Green D E and Golovashchenko S F 2017 Formability enhancement of DP600 steel sheets in electro-hydraulic die forming *J. Mater. Process. Technol.* **244** 178–89