New Technologies to Form Light Weight Automotive Components

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Abstract
This paper presents an overview of advances in sheet metal forming to enhance forming of lightweight materials such as Ultra/Advanced High strength Steel (U/AHSS), aluminum alloys and magnesium alloys for autobody panels. Advances in conventional stamping and sheet hydroforming such as multipoint cushion system, flexible blank holder, and new processes such as warm stamping/sheet hydroforming for aluminum and magnesium alloys, hot stamping for boron steels are discussed. Practical examples of application of advanced forming technology for autobody panel manufacturing are presented.

Keywords:
Sheet metal forming, Sheet hydroforming, Warm sheet forming

1 INTRODUCTION

Increase in demand for fuel efficient vehicles along with higher safety and environmental standards has forced automotive manufactures to look for means to reduce the weight of the vehicle and improve its strength for passenger safety against crash. Among the different parts in an automobile, the chassis and the body "Body in White" (BIW) parts represents 25% to 35% of the total weight depending on the vehicle and it protects the passenger from the crash. Hence the focus of the research in automotive industry has been devoted to development of better designs and application of new materials that would increase the strength and reduce the weight of the BIW parts/vehicle.

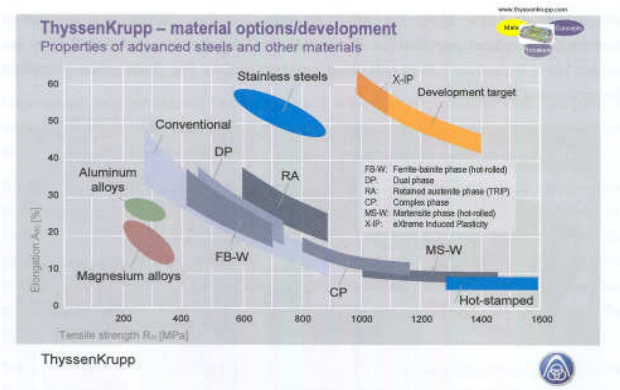


Figure 1 Material properties of various sheet materials used in BIW parts [1]

Conventionally BIW parts are made by stamping process from draw quality steels. Light weight materials such as aluminum alloys, magnesium alloys and A/UHSS steels (DP steels, TRIP steels, CP steels, TWIP steels, and MS-W steels) offers alternative choices to select materials for BIW parts due to its high strength to weight ratio compared to conventional steel. However, the lightweight materials are characterized with low formability compared to conventional steels and pose a significant challenge in manufacturing the BIW parts by stamping [Figure 1]. Also, springback in the formed part from lightweight alloys is high compared to steels, resulting in difficulty in assembly. Hence, the application of lightweight materials to BIW parts was restricted to shallow parts due to the constraints in manufacturing.

In this paper, advances in sheet metal forming technology such as multipoint cushion systems in stamping, new processes such as sheet hydroforming, warm forming and hot stamping that are being developed to address the need for improving forming technology to process light weight materials, are described. Practical examples of application of advanced forming technology for autobody panel manufacturing are presented.

2 STAMPING – MULTIPOINT CUSHION SYSTEMS

In stamping, the quality of a formed part is determined by the amount of material drawn into the die cavity during the forming process. Excess material flow will cause wrinkling while insufficient material flow will cause tearing in the part. The material flow into the die cavity is influenced by the Blank Holder Force (BHF), and the blank shape for a given interface friction condition between the sheet and the tooling.

Conventionally, BHF is applied uniformly on the blank holder surface and held constant during the forming process. However, material flow is not uniform along the perimeter of the die. The material flow is restricted along the corners while metal flows easily into the die cavity along the straight edges. Hence, draw beads are mainly used to regulate the material flow while blank holder force is used to just avoid opening of the die/blank holder during the forming process. The draw bead geometry and the size are usually decided in die tryouts. During production, abrasive wear (for Advanced and Ultra High Strength Steels - A/UHSS) and adhesive wear (for aluminum alloys), causes change in the draw bead geometry and in the friction conditions. Hence draw beads in the dies need frequent maintenance to produce consistent parts. Also, draw bead dimensions are finalized in tryout for a given coil of sheet metal while in production, the properties of incoming sheet materials changes with the coil especially for A/UHSS steels. Hence the draw beads obtained during die tryouts could result in higher scrap depending on the coil. Thus, the current process is not robust enough to accommodate variations in the material property of the incoming material and natural wear and tear of the tooling in long run.

Control of material flow during the deep drawing process by both the blank holder force and the draw beads allows us to accommodate for the change in the material properties as well as the wear in the draw beads by just changing the blank holder force from part to part or coil to coil thereby avoiding frequent die maintenance. However, this requires the capability to apply different blank holder force at different locations of the blank holder.

Modern presses are equipped with multipoint cushion systems that consist of several individual cylinders to directly apply the force on the blank holder [Figure 2]. The cylinders can be programmed independently to apply different force [2, 3]. Also, currently dies are built with hydraulic or nitrogen cylinders mounted in the lower /upper die shoe to apply the blank holder force variable in location and during stroke [4] [Figure 3]. Hence BHF can be varied with location and with stroke to better control material flow thereby enhancing the formability of the materials (especially low formability light weight materials) [3]. Similar technology is widely used in forming stainless steel sinks [1].

However this capability is under utilized in automotive production because (a) it is difficult to estimate the BHF need to be applied by each cushion pin in die tryouts, and (b) conventional sheet materials can be formed with existing method of constant blank holder force. The increase in the complexity of the parts and emphasis to use lightweight materials with low formability requires the use of multi-point cushion capabilities to better control the material flow and expand the operating window of the forming process. Successful application of a multi-point cushion system to form the part requires a methodology to estimate the necessary blank holder force that can be refined in tryout for production.

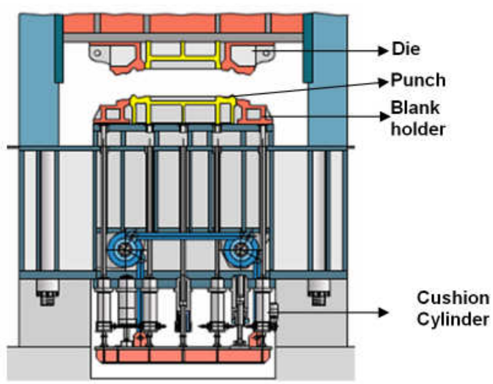


Figure 2 Schematic of the multipoint cushion unit in the press [4]

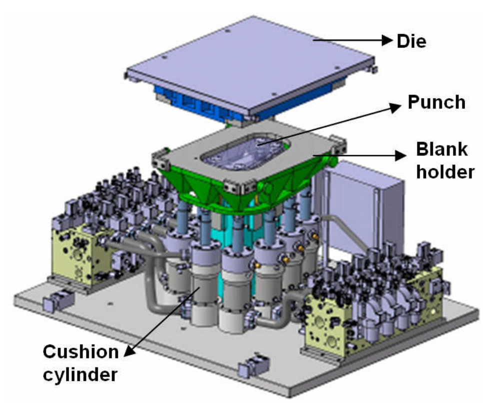


Figure 3 Schematic of the multipoint cushion unit mounted in the tooling [4]

CPF in cooperation with USCAR consortium (Project AMD-301 – Flexible Binder Force Control) developed a numerical optimization technique coupled with finite element analysis of the stamping/sheet hydroforming process to predict four possible modes for application of BHF, namely (a) BHF constant in space/location and time/stroke, (b) BHF variable in time/stroke and constant in space/location, (c) BHF variable in space/location and constant in time/stroke and (d) BHF variable in space/location and time/stroke for a multipoint cushion system as well as single point cushion system/nitrogen cylinders.

The developed methodology was used to predict the BHF to form an automotive part (liftgate-inner) from AA 6111-T4 aluminum alloy thickness 1.0 mm, DP500 material thickness 0.8 mm and BH210 steel thickness 0.8 mm. Figure 4 shows an example BHF predicted by the developed optimization routine using FE simulation of the forming process for aluminum alloy A6111-T4. Similar force profiles were also estimated for BH210 steel and DP500 steel. The developed force profiles were used in tryouts to form the part from different sheet material using the same die without making any physical modification to the die. It was observed that the part could be formed from three different materials and thicknesses by just changing the BHF applied by cushion pins (Figure 5). It should be noted that the liftgate –inner part could not be formed by AL6111-T4 material despite repeated trials using conventional single point system. This demonstrates the capability of the multipoint cushion system to enhance the operating window of the conventional stamping process to form autobody panels from lightweight materials. Also, the increase in the robustness of the process to form different sheet materials and thicknesses is demonstrated.

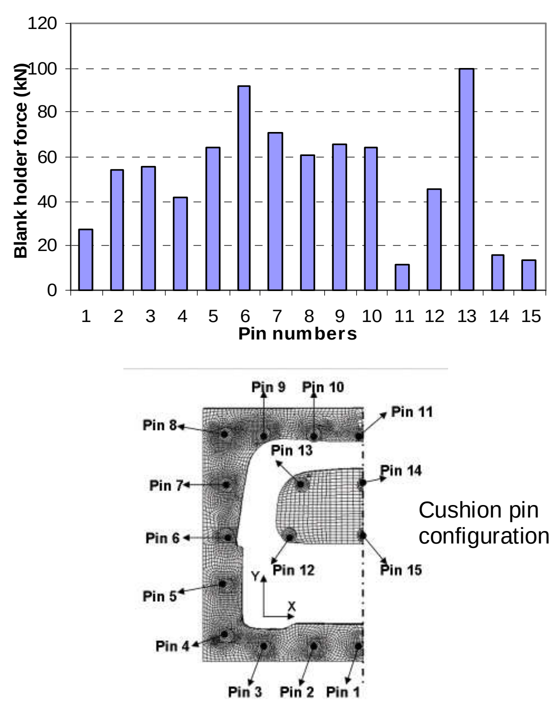


Figure 4 Optimum blank holder force variable in space and constant in time (predicted by optimization for forming the lift gate part from aluminum alloy A6111-T4 of 1 mm thickness)

A6111-T4, t = 1.0 mm **BH 210, t = 0.8 mm** **DP 500, t = 0.8 mm**

Figure 5 Schematic of the formed liftgate part from three different materials with different thicknesses in the same die by modifying BHF applied by the multipoint cushion system.

3 SHEET HYDROFORMING

Sheet hydroforming process is an alternative to stamping process where either the punch or the die is replaced by a hydraulic medium, which generates the pressure and forms the part. Sheet hydroforming is classified into two types SHF-P and SHF-D: In sheet hydroforming with punch (SHF-P) (Figure 6), the hydraulic fluid replaces the die while in the sheet hydroforming with die (SHF-D) (Figure 7), the hydraulic fluid replaces the punch. Between the two processes, SHF-P is widely used.

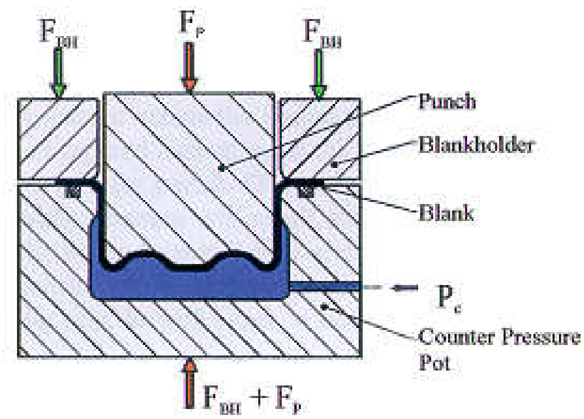


Figure 6 Schematic of the SHF-P process [6]

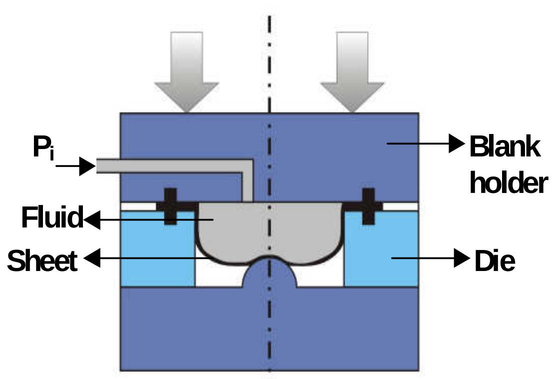


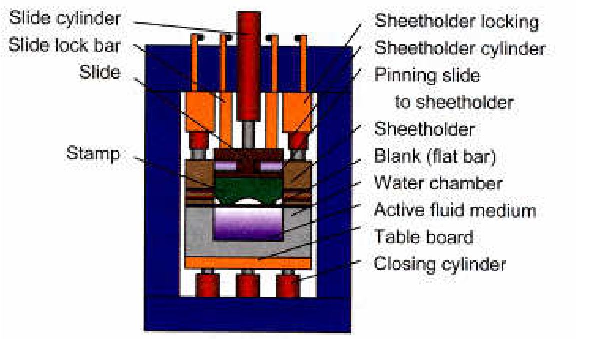
Figure 7 Schematic of the SHF-D process

3.1 Sheet Hydroforming with punch (SHF-P)

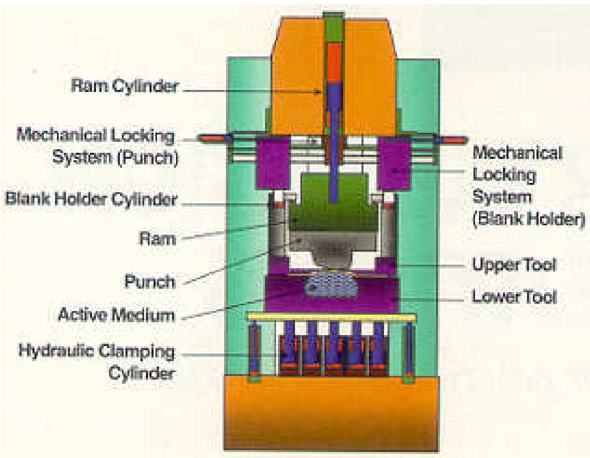
In SHF-P, the sheet is deep drawn against a counter pressure in the pot rather than a female die in regular stamping operation (Figure 6). The medium in the pressure pot can be either "passive" (pressure generated due to the incompressibility of the medium during forward stroke of the punch) or "active" (pressure generated by external pump). SHF-P process results in higher drawability compared to conventional stamping because in this process, the sheet metal is forced to form against the punch surface due to the fluid pressure. Due to friction between the sheet and the punch surface, the sheet in contact with the punch surface is not stretched during the forming process resulting in uniform wall thickness leading to higher drawability. Thus, SHF-P is an attractive option for forming sheet metal from low formability lightweight materials despite its low cycle time. Furthermore, there is no need for a female die, resulting in lower die costs. Hence SHF-P process is currently being considered for production of automotive body panels. For example, General Motors uses the SHF-P process to manufacture body panels of Pontiac Solstice with the help of Amino Corporation, Japan [7].

Presses

Intelligent press design and advancement in hydraulics and control has significantly reduced the cycle time of SHF-P process. SHF-P presses are designed using the short stroke design concept [Figure 8]. The top die is moved up and down using the long stroke cylinder that requires large volume of the hydraulic fluid at low pressure. The ram is indexed at the desired bottom position using the mechanical locks. Short stroke cylinders that are mounted in the bottom are activated during SHF-P to apply the large force required to counteract the force generated on the punch due to the pot pressure. Short stroke cylinders require less volume of fluid at high pressure. The new machine concept allows: (a) independent control of the BHF and pot pressure, and (b) a reduced cycle time and cost by decreasing the amount of high pressure hydraulic fluid to be handled by the system.



a) Schnupp HMT [8]



b) Thyssen Krupp

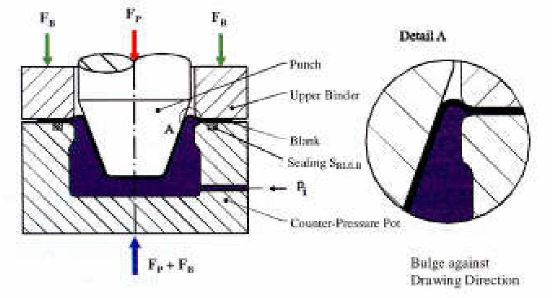
Figure 8 Schematic of the SHF-P presses built by Schnupp HMT and Thyssen Krupp hydromechanics [8]

Tool design

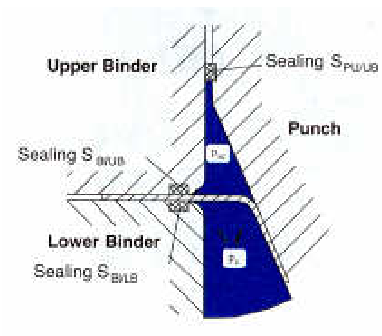
The concept for tool design is similar to regular stamping. The punch and blank holder are specifically designed to the part shape while the pressure pot remains common for all parts. The pressure pot and the punch in SHF-P tool should be designed to withstand high pot pressure. Also, careful consideration is required for sealing at the pressure pot – sheet interface to avoid leakage of the fluid during SHF-P.

Various advancements in tool design are:

1. <u>Pressure chamber at top to overcome bulging:</u> SHF-P for parts with tapered sidewalls result in the bulging of the sheet in the gap between the blank holder and the punch as shown in Figure 9a (Detail A) due to high pot pressure during forming. This bulging could result in excessive thinning and fracture at higher pot pressure. University of Stuttgart - IFU has developed new tooling design with additional sealing at the punch-blank holder interface as shown in Figure 9b to create a pressure chamber in the top. During SHF-P the hydraulic fluid from the pot is circulated to the top pressure chamber so that the pressure in the top and bottom chamber is the same to avoid bulging [6].



(a)



(b)

Figure 9 Schematic of the bulging during SHF-P using punch with tapered wall and upper chamber to compensate for bulging during SHF-P using punch with tapered wall [6]

2. <u>Elastic cushion to form sharp corners:</u> The pot pressure required to completely form the part depends on the smallest corner radius in the part. Thus, parts with sharp corners require presses with very high capacity resulting in increase in the investment cost. Schuler developed elastic cushions that are mounted in the pressure pot as shown in Figure 10. Towards the end of the forming process, the sharp corners are formed mechanically by the cushions rather than the pot pressure resulting in reduction of the required press capacity and investment [9].

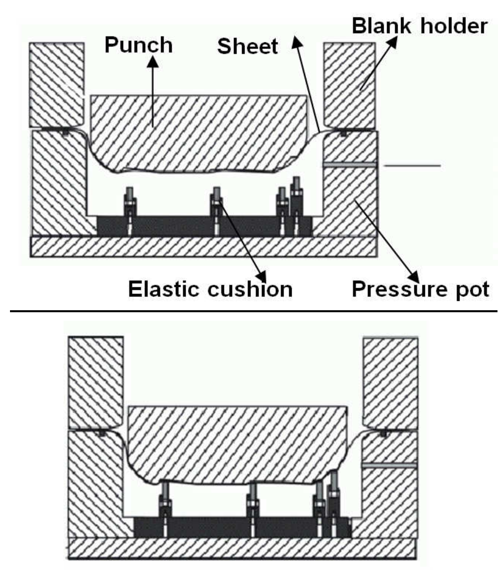


Figure 10 Schematic of the pressure pot with elastic cushions to form sharp corners in SHF-P [9]

3. Elastic blank holder: Design of blank holder plays a dominant role in SHF-P because the applied blank holder force controls the material flow during drawing and also applies the necessary force to avoid leakage of the pressure medium during forming process. In forming asymmetric parts using conventional blank holders, thickening in the flange is not uniform resulting in gap between the rigid blank holder and sheet at thin locations that causes leakage of the pressurizing media. University of Stuttgart - IFU developed a multipoint-segmented elastic blank holder similar to stamping as shown in Figure 11. The thin plate on the blank holder that comes in contact with the sheet deflects elastically depending on the contact sheet thickness; thereby it remains in uniform contact with the sheet. Thus, segmented elastic blank holder applies uniform pressure and avoids leakage of the pressurizing medium compared to conventional rigid blank holders. Multipoint cushion systems are also preferred in SHF-P process as in stamping to better control the material flow.

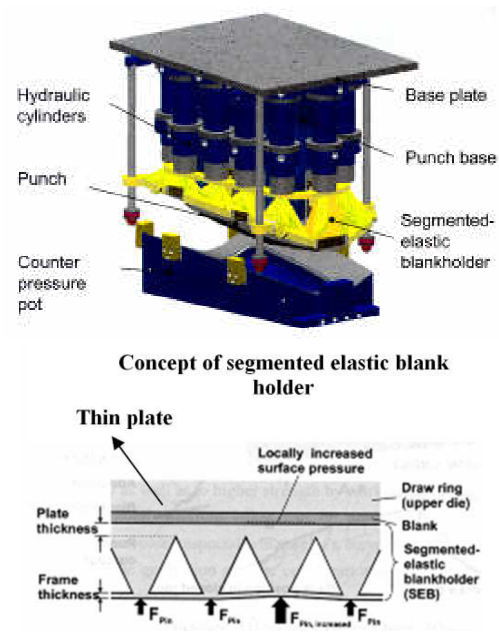


Figure 11 Schematic of the die assembly with segmented elastic blank holder for SHF-P [10]

Process control

In SHF-P process, process parameters – namely, the variation of pot pressure with punch stroke and the variation of BHF with the punch stroke - significantly influence the material flow. Lower value of pot pressure results in a process similar to stamping; thereby benefits of SHF-P cannot be realized. Higher pot pressures could lead to prebulging and eventually bursting at the bulged locations. Also, the BHF should be high enough to avoid the leakage of the pressurizing medium but at the same time allow easy material flow from the flange. Hence, it is necessary to estimate the "optimum" process parameters to form the parts with no defects. CPF developed an optimization technique coupled with FE simulation to estimate the optimum process parameter (BHF vs. stroke and pot pressure vs. stroke) to form a round cup by SHF-P process without wrinkling and failure. Figure 12 shows the predicted optimum process parameters obtained using the developed technique, for forming a round cup of diameter 90 mm of depth 100 mm (Limiting Draw Ratio - LDR 2.5) from AKDQ steel by the SHF-P process. The predicted BHF and the pot pressure varying with punch stroke were used in the experiments conducted at Schnupp Hydraulik, Germany. The part was formed using the predicted optimum BHF with negligible amount of leakage of the medium, no wrinkling and no split. Thinning distribution predicted by FE simulation was compared with the experimental measurements, Figure 13. The predictions were good [11]. The developed technique was also used to estimate process parameters for trunk-lid from EDDQ steel (Figure 14) [12].

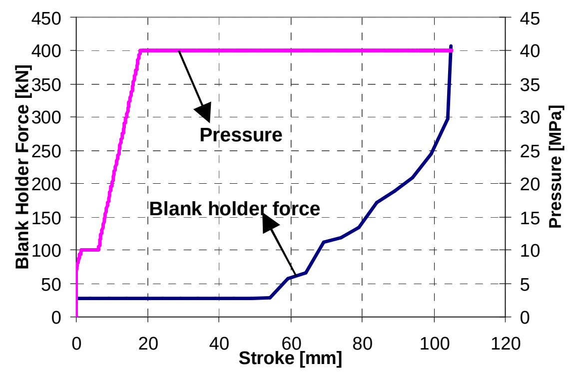


Figure 12 BHF and pot pressure varying with the punch stroke estimated by numerical optimization technique coupled with FE simulation.

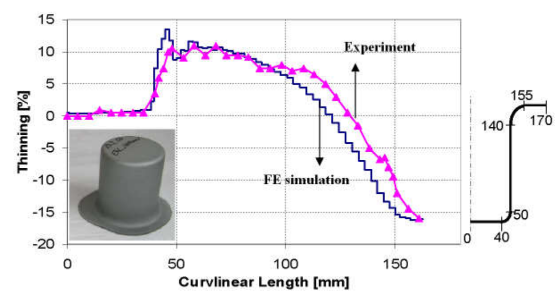


Figure 13 Comparison of thinning distribution obtained from FE simulation and experiment. (Inset: Round cup of 90 mm diameter formed using the optimized pressure and BHF)

Figure 14 The formed part (trunklid – outer) using BHF variable in space and constant in time, predicted by FE simulation. The test was conducted at KIA Motors, S. Korea.

4 WARM FORMING OF ALUMINUM ALLOYS

Aluminum alloys 5XXX series (Aluminum – Magnesium alloy) and 6XXX series (aluminum-silicon alloy) are used for automotive production for body panels. Application of 5XXX series is limited to shallow parts due to its low formability compared to steel. Also, 5XXX series alloys are used for only inner panels due to the presence of the *lüder* lines in the formed part that affect its appearance.

The 6XXX alloys are limited to shallow outer body panel due to its low formability. Aluminum alloys show increased formability when processed at elevated temperatures and also the *lüder* bands disappear when formed at elevated temperature [13].

The USCAR consortium in cooperation with DOE conducted a detailed study on the development of warm forming technology for forming aluminum alloy body panels. Commonly used 5XXX alloys AL5754, AL5182+MN, AL5182-O and 6XXX series alloy AL6111-T4 were selected for investigation. Tensile test and biaxial tests were used to evaluate the formability and the forming limit diagrams. Among the selected alloys, AL6111-T4 showed relatively lesser improvement in formability with increasing temperature, indicating no potential benefits in forming at elevated temperature. However, the formability of both the 5XXX series alloys increased significantly with temperature. At forming temperature of 300^{o}C to 350^{o}C, they showed even higher formability compared to conventional draw quality steels. Among the 5XXX series alloys, AL5754 deformation was very sensitive to the temperature compared to AL5182+MN and AL5182-O alloy [13, 14]. Therefore, AL5182+MN, AL5182-O alloy was selected for use in the warm forming process for better process control. The selected alloy was used in heated dies to form Chrysler *Neon* door inner from AL5182+Mn at forming temperature of 350^{o}C (Figure 15). The part could be formed from AL5182+Mn without surface defects and *lüder* lines. Also little springback was observed in the part compared to room temperature forming thereby eliminating potential assembly problems [14].

At CPF, the influence of temperature and forming velocity on the deep drawability of round cups of diameter 40 mm from AL5754-O was investigated. In the experiments, the die and the blank holder are heated to the desired temperature while the punch is cooled [Figure 16]. Round cups of LDR = 2.6 could be drawn at temperature of 300^{O}C even with higher forming velocity 18 mm/sec [15]. Groche et al 2002 [16] investigated the warm SHF-P process for aluminum alloys. In warm SHF-P process, the sheet and the flange portion of the die and the blank holder are heated to the required temperature as shown in Figure 18. The punch is cooled while the pressurizing fluid temperature is kept slightly higher than the room temperature. During the SHF-P process, the lower temperature of the punch and the pressurizing medium cools the sheet adjacent to the punch thereby the strength of the sheet is increased to carry the load during drawing and postpone failure due to the excessive thinning. As a result, an LDR of 3.0 was obtained for aluminum alloy round cup at forming temperature of 250^{o}C. Thus, the warm forming process significantly enhances the deep drawability of aluminum alloys and encourages an increase in the use of lightweight aluminum alloys for autobody panels.

Figure 15 Schematic of the Dodge *Neon* door inner formed by the warm forming process [14].

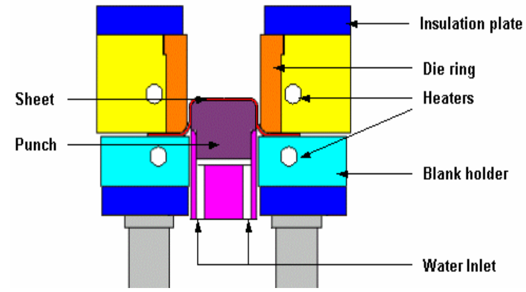


Figure 16 Schematic of the warm deep drawing tooling used for experiments conducted by CPF.

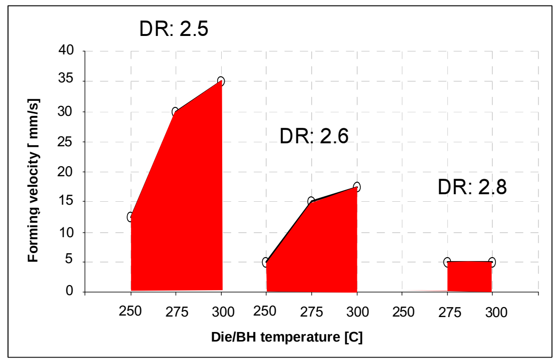


Figure 17 Deep drawability of AL5754-O estimated as a function of die and blank holder temperature and forming velocity through round cup deep drawing experiments [15]

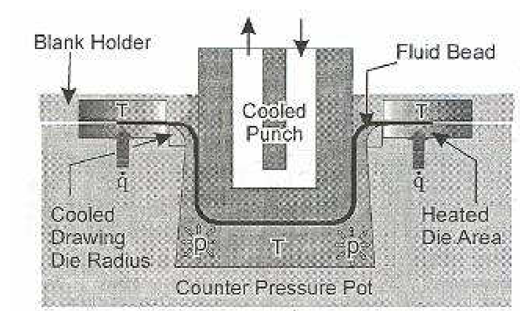


Figure 18 Schematic of warm hydromechanical deep drawing tooling (SHF-P process) at University of Darmstadt, Germany [16]

5 QUICK PLASTIC FORMING OF ALUMINUM ALLOYS

Quick plastic forming is an innovative process developed by General Motors. It is similar to sheet hydroforming process with die/super plastic forming where the heated sheet metal is formed against the die using the pneumatic pressurizing medium. This process was exclusively developed to form parts from aluminum alloy AL5083 that has higher uniform elongation at higher strain rates and temperature of 450^{o}C. The strain rates in the process are higher (10^{-3} s^{-1} to 10^{-1} s^{-1}) compared to the super plastic forming (10^{-4} s^{-1}) thereby considerably reducing the cycle time. Also, the forming temperature is less (450^{o}C) compared to 500^{o}C for super plastic forming. The input blanks required for quick plastic forming are similar to conventional stamping and do not require fine grain size as in super plastic forming thereby reducing the input material cost. Due to high cycle time, and relative lesser operating cost compared to super plastic forming, it is economical for auto body production [17].

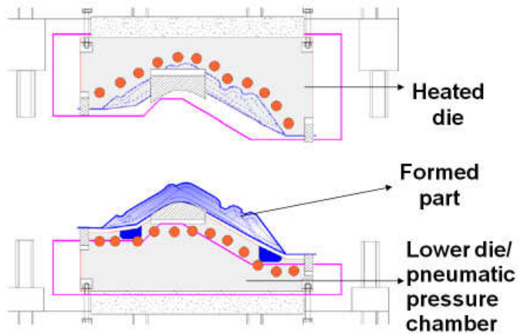


Figure 19 Schematic of the heated tool for QPF [17]

Figure 20 Schematic of the inner and outer panel of Malibu X deck lid formed by quick plastic forming processes [17]

6 WARM FORMING OF MAGNESIUM ALLOYS

Magnesium (Mg) alloys offer great potential to reduce weight by replacing the most commonly used materials, i.e. steel and aluminum, because of their low density. The use of conventional forming technology for Mg alloy sheet is restricted because of their low formability at room temperature. However, Mg alloys show increased formability in the temperature range of 200°C to 300°C. This is due to the activation of additional slip planes (pyramidal plane <1101>) in their Hexagonal Closed Packed structure [18].

Droder 1999 [18] conducted an extensive experimental investigation on the forming properties of Mg alloys. He used AZ31B and AZ61B in his experiments. He observed that round cups of 100 mm diameter could be drawn to a maximum height of 120 mm [LDR = 2.5] at a forming temperature of 200°C, while rectangular pans (110 mm x 220 mm) could be drawn to a maximum height of 65 mm at 225°C. Punch temperature during the process significantly influenced the Limiting Draw Ratio (LDR). Maximum LDR was obtained when the punch was maintained at room temperature. In the deep drawing process, the punch force is transmitted through the cup wall to the deformation zone in the flange. Lower punch temperature cools the punch wall thereby increasing the flow stress and the ability to carry higher deep drawing load. Similar observations were also made by Yosihara, et al. 2003 [19]. In forming non-symmetric pans, drawability of Mg alloys at elevated temperatures could be further increased by locally varying the temperature in the tool. Rectangular pan (110 mm x 220 mm) was drawn up to a depth of 98 mm by maintaining high temperature at tool corners (higher deformation zones and low temperature at straight edges (lower deformation zones) thereby better controlling the material flow [20].

At CPF, the influence of temperature and the forming velocity on the deep drawability of the round cups of diameter 40 mm for Mg alloy AZ31B-O were investigated [Figure 21], [15]. In the experiments, the die and the blank holder are heated to the desired temperature while the punch is cooled [Figure 16]. Round cups of LDR = 2.8 could be drawn at temperature of 275°C with a forming velocity 35 mm/sec indicating the tremendous potential in warm forming of Mg alloys at elevated temperature for mass production of autobody panels.

Behrens, et al. 2004 [21], Jäger 2005 [22] investigated warm sheet hydroforming with punch process using round cup tooling. Benefits of both the SHF-P process and the warm forming process further enhanced the drawability of the Mg alloy sheet. In warm SHF-P process, maximum LDR of 3.0 could be obtained for Mg alloy sheet at relatively lower temperature of 150°C. Jäger 2005 [22] also investigated the warm SHF-D process using pneumatic medium to form Mg alloy sheets at elevated temperature against the die. Inner door reinforcement could be formed from Mg alloy AZ31B at a temperature of 400°C but at very slow strain rates in the range of super plastic forming.

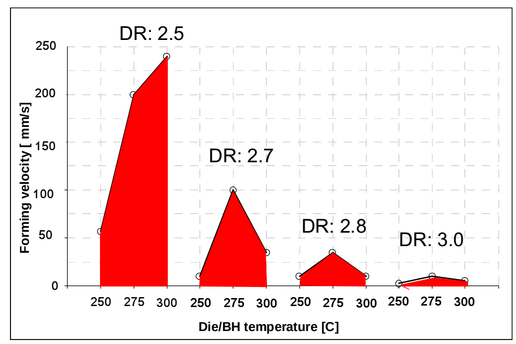


Figure 21 Deep drawability of magnesium alloy AZ31B estimated as a function of die and blank holder temperature and forming velocity through round cup deep drawing experiments [15]

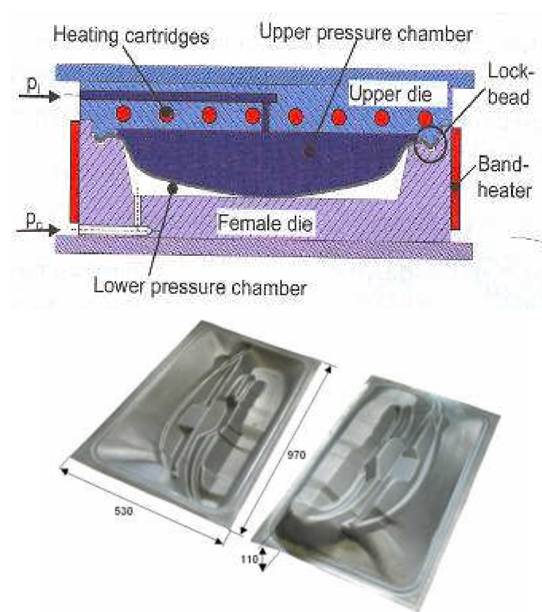


Figure 22 Schematic of the tooling and the inner door reinforcement formed from magnesium alloy at forming temperature of 400°C [22]

7 HOT STAMPING OF BORON STEELS (22MNB5)

7.1 Process description

Boron steels are high strength steels obtained by alloying of manganese and boron. In this process, boron steel blanks are heated up to an austenizing temperature of 900 to 950^{o}C and formed in a cold die at high velocity (strain rate). After drawing depth is reached, the part is kept under pressure against the die and is cooled by the dies. Controlled cooling in the die causes tempering (martensitic transformation) of the formed sheet material resulting in higher strength. The cycle time for this process (stamping + cooling in the die) is around 15 to 25 sec. Part is removed from the die at temperature of 150^{o}C and has a yield strength of 1000 MPa – 1200 MPa, ultimate tensile strength of 1400 MPa – 1600 MPa and elongation of 6%. Currently hot stamping parts are used in front and rear bumpers, A-pillars, B-pillars, roof rails frames, etc., to improve strength/safety of the vehicle against impact/crash [23, 24, 25, 26].

7.2 Process types

The hot stamping process is classified into two types (a) Direct process and (b) Indirect process.

Direct process

In direct process, the sheet metal initially blanked from the coil is heated up in a furnace to the austenizing temperature of 900^{O}C – 950^{O}C in a controlled atmosphere to avoid any scaling. The heated blank is quickly transferred to the die where it comes in contact with oxygen and could form some scales on the surface. The sheet metal is quickly formed at high speed and control-cooled in the die to get the desired material properties (Refer Figure 23). The parts are subsequently laser trimmed to get the final part. The use of trimming dies after forming is limited due to high strength of formed part, resulting in significant wear of the tools. Depending the sheet coating, the parts are cleaned by shot-peening or sand-blasting to remove scales for painting. The disadvantage of this process is that the part geometry should be such that it can be formed in one step as any post forming operation cannot be performed due to the high strength and low formability of the hot stamped part [23].

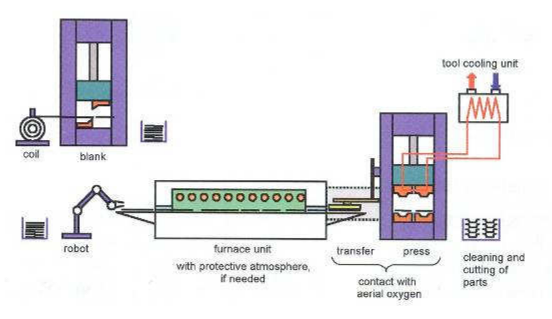


Figure 23 Schematic illustrating the direct hot stamping process [23]

Indirect process

In indirect process, the part is initially pre-formed to a partial shape of the final part. The pre-formed part is later hot stamped to the final part geometry using the same process chain as explained in the direct process (Refer Figure 24). Through the pre-forming process, additional forming can be accommodated to form the part. The indirect process is limited to uncoated sheet. In case of coated sheets, the initial forming operation would result in ripping and flaking of the born steel coatings resulting in problems during hot stamping [23].

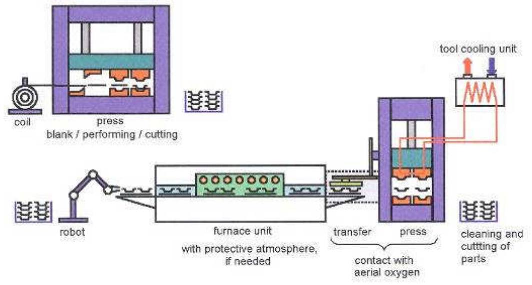


Figure 24 Schematic illustrating the indirect hot stamping process [23]

7.3 Process control

In this process, mechanical properties of formed part depends on (a) input sheet material properties, (b) initial heating in furnace, (c) process conditions during forming and (d) controlled cooling in the die [23, 24, 25, 26].

Input sheet material

Conventionally, high strength steels are manufactured by hot rolling process followed by cold rolling and annealing. During annealing, recrystallization takes place to relieve the cold working. Boron steels used in hot stamping also follow the same process; the hot stamped part has higher strength but low elongation thereby reducing the energy absorption capacity of the structure during crash. Volkswagen developed an alternative process to manufacture boron steels for hot stamping. Boron steels were annealed partially (40 %) during the annealing phase. Partially annealed sheets when hot stamped resulted in much smaller grain size thereby improving the elongation in the hot stamped parts from 6 to 10 % while maintaining the same strength [26].

Initial heating in the furnace

The heating time, temperature and coating of the sheet significantly affect the quality of the formed part. Depending on the composition, the blanks are heated between 900 to 950^{O}C for 300 sec. Decrease in heating temperature reduces the austenization in the blank thereby resulting in existence of multiple phases in the part which reduces the strength and elongation of the formed part. Decrease in the heating time also has a similar effect [25]. During heating, uncoated sheets should be protected from oxide formation using inert gases. Arcelor has developed a precoated boron steel USIBNOR 1500P especially for hot stamping which while heating forms alloyed layer of Fe-Al-Si on the substrate and protects from any oxides and corrosion thereby avoiding scales. Hence post-forming operations such as shot-peening are eliminated [25].

Process conditions for forming

During forming, the velocity of the forming influences the quality of the formed part. The forming speed should be high enough to form the blank before it loses the temperature and should not be too high to initiate failure as formability decreases with increase in speed [26].

Controlled cooling in the die

Several factors influence cooling of the part in the dies. (a) Design layout of cooling channels in the dies, (b) material properties of the dies and their coatings, (c) forming temperature, (d) flow conditions of cooling medium, (e) cooling medium temperature, (f) forming force/pressing force and (g) cooling time in the die. This poses a significant challenge on design/maintenance of hot stamping tools compared to conventional stamping. Also, even though forming force is less, thermal fatigue due to continuous cooling and heating could significantly reduce tool life. Cooling channel layout in the dies is designed using FE simulation to obtain uniform cooling and therefore, uniform material properties in the formed part. Trumpf has developed new technology for manufacturing dies with desired cooling channel layout. The tubes of cooling channels are initially welded and fixed to the pattern for casting of the die. Thus, the cast die has cooling channels at desired locations thereby avoiding expensive machining [24, 25].

8 SUMMARY AND CONCLUSIONS

In this paper an overview of advances and ongoing research in sheet metal forming technology to meet the demands for processing light weight materials such as aluminum alloys, magnesium alloys and A/UHSS steels for autobody panels is presented. Advancements such as multipoint control system in stamping, sheet hydroforming, warm forming and hot stamping improves the drawability of the low formability light weight materials thereby enhancing its use in autobody panels to improve vehicle safety and reduce weight.

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