B. Active Flexible-Binder Control System for Robust Stamping (AMD 301[i])

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Objective

- Develop and demonstrate, on an industrial scale, an optimized, closed-loop, flexible-binder control system that can be installed in presses to improve the quality, reduce the variability, and maintain the accuracy of stampings made from aluminum alloys and ultra-high-strength and stainless steels. The system will also reduce cost for developing and setting production tools.

Approach

- Conduct open-loop control demonstration of flexible-binder technology.
- Develop methodology and guidelines for designing and building flexible binders.
- Develop computer simulation and process optimization capabilities for flexible binders.
- Develop a closed-loop, flexible-binder control system with appropriate sensors.
- Demonstrate closed-loop control of the flexible-binder system on industrial parts.
- Evaluate the technical and economic feasibility of flexible-binder technology.

Accomplishments

- A multi-point cushion system with 26 independently-controlled hydraulic cylinders was used to demonstrate flexible-binder control technology on a full-size General Motors (GM) liftgate inner. The system enabled the stamping of liftgate panels from three different sheet metal alloys (A6111T-4, bake-hardenable (BH) 210 and dual-phase (DP) 500) and various thicknesses (0.7-1.0 mm). This was accomplished by implementing appropriate binder load trajectories for each material using software-based adjustments without the need to modify or adjust the stamping tools.
- Completed trials and demonstration on the GM liftgate inner using optimized binder-force trajectories that varied in location and stroke. The demonstration showed that finite-element analysis (FEA)-based optimization

can provide effective initial settings for tonnages and these settings can be easily modified to obtain good parts. In addition, shop-floor press operators ran the software and demonstrated that the user interface with the system has minimal operational complexity.

- The system reduced the die-tryout time by about 80%. Splits and wrinkles could be eliminated or reduced in minutes by adjusting the tonnages of the appropriate cylinders.
- Conducted closed-loop trials and demonstration in a mechanical press using a new, 10-cylinder, binder-load control unit with large pan tooling. The unit was equipped with feedback control system and wrinkle-height sensors.
- Assessed the room-temperature forming of magnesium (Mg) alloys. Conducted stamping tryouts of the GM liftgate inner using Mg alloy AZ31B.
- Demonstrated the binder-load control unit with the rigid wheelhouse tooling.
- Reviewed manufacturing benefits and value of flexible-binder control technology.

Future Direction

There is some discussion on the course of future work with respect to performing die work. One approach is that the die should receive minimal work before the maximum benefit of changing cylinder loads is evaluated with the die in the "as cut" condition. An alternative approach is that the die should be worked to produce as good a panel as possible without the use of cylinder-load variation, and the cylinders would then be used only to improve the part as much as possible. The final strategy will need to be resolved before pursuing implementation and commercialization of this technology.

A number of steps must be taken before all the benefits of this technology can be brought to the production readiness stage:

- Design, build and test a movable, multi-point cushion system that can be used with various dies to produce different parts. Hydraulic cylinders should be capable of re-configuration in space to accommodate various part shapes and geometries.
- Design, build and test more efficient valves and controllers.
- Design and build a more efficient and simplified hydraulic system to circulate oil.
- Develop efficient, closed-loop process controllers for friction and draw-in sensors.
- Conduct a full-scale economic feasibility study of this technology.
- Develop efficient simulation/optimization codes to reduce computing time for load-trajectory optimization.
- Develop criteria for best application of the technology (type of parts and presses).
- Develop plans to integrate this technology into the stamping plant.
- Involve leading press manufacturers in developing, retrofitting, integrating and implementing hydraulic cushions in their presses.

Introduction

Significant effort is spent on fine tuning dies to eliminate wrinkles or splits in formed panels. Fine tuning the die is an iterative process of welding, grinding, polishing and testing to produce defect-free parts. This process is disruptive, time consuming, frustrating and expensive. Also, there is an increasing demand for using lightweight materials in the transportation industry; however, such materials are less formable than the low-carbon steel that they are replacing. This has pushed the stamping industry to consider alternative methods to forming lightweight and high-specific-strength materials. Recently, innovative binder concepts with optimized computer simulation and advanced press controls have led to the development of flexible-binder load-control systems. Such systems can be built and installed in existing mechanical presses to allow better control of the forming process.

A hydraulic cushion unit consisting of 26 independently-controlled hydraulic cylinders with liftgate tooling was built and successfully installed in a mechanical press to produce panels from different sheet metal using the same set of tools. Binder-force trajectories generated by both trial-and-error and FEA simulation were implemented and liftgate panels from BH210, DP500 and A6111-T4 were successfully made. The tryout time using the system was considerably less than that using the conventional method of working the die. Stamping trials have shown that the new flexible-binder control technology can improve part quality, enhance process robustness, and reduce the time and cost for die tryout and fine tuning. The ability of binder-load control technology to influence manufacturability using a rigid wheelhouse die was also demonstrated.

Computer Simulation and Optimization

Traditionally, the binder force is applied uniformly on the binder surface and held constant during the forming process. Also, the magnitude of the binder force for a given part is determined based on past experience and trial and error. Many studies have shown that variable binder-force trajectories increase the formability and improve dimensional accuracy of stamped complex parts. Hydraulic cushions with programmable multi-pins are commercially available on some mechanical transfer presses, but programming such pins proved to be challenging for press users. Currently, such presses are set up using extensive trial and error that results in long tie-ups of those presses.

An optimization algorithm was developed and implemented in the simulation code to predict optimum constant and variable binder-force trajectories in multi-point cushion systems. Computer simulation was successfully used to determine the temporal and spatial binder-force trajectories for the flexible-binder with the liftgate tooling shown in Figure 1.

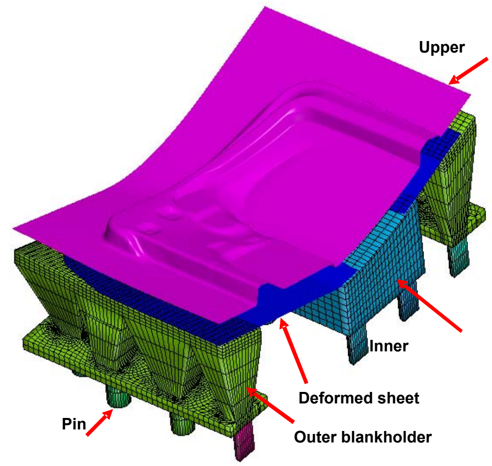

Figure 1. Finite-element modeling (FEM) model of flexible binder for the liftgate inner die.

Pin numbers and locations with respect to the liftgate simulation are shown in Figure 2. Due to symmetric boundary conditions, only 15 pins (pins 1- 15) were considered in the analysis. Finite-element (FE) simulations coupled with optimization techniques were used to estimate the optimal binder force required for each cushion pin to form the liftgate inner part. In this study, part thinning and wrinkling were the only parameters used to monitor part quality. The tolerable wrinkle amplitude was 0.05 mm. Wrinkles on the sidewall were not monitored because those wrinkles were found to be insensitive to the binder force.

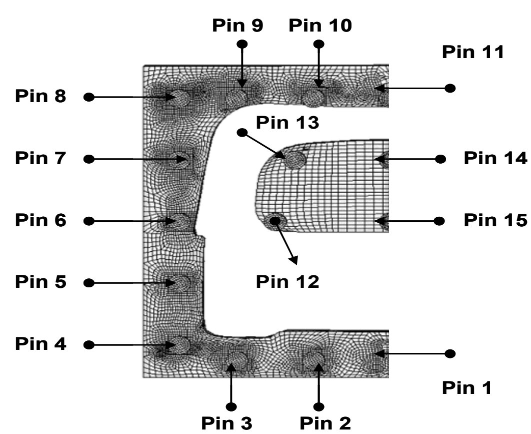

Figure 2. Pin numbers and locations in the liftgate simulation.

Three materials, 1) BH210 steel of thickness 0.818 mm, 2) Aluminum (Al) alloy A6111-T4 of thickness 0.998 mm and 3) DP500 steel of thickness 0.785 mm, were used to stamp liftgate inner panels. Different materials and thicknesses were selected to demonstrate that flexible-binder technology can accommodate variations in materials by simply adjusting the individual pin forces in the multi-point cushion system.

In multi-point cushion systems, four modes of applying binder forces on pins during the forming process are possible. Table 1 shows the effect of trajectory mode on maximum thinning in the simulated liftgate. Optimum binder-force trajectories for the four modes were predicted and analyzed.

Mode 1 and Mode 2 trajectories produced maximum thinning of 27% and 25%, respectively. Those strains were high enough to cause splits in the formed panels. Mode 3 and Mode 4 trajectories produced maximum strains of about 23%, which are still high but is less than those produced by trajectories of the other two modes.

Tryouts have shown that panels made by using Mode 3 and Mode 4 binder-force trajectories either had no splits or that the splits were corrected by slight trial-and-error adjustment of the pin forces in the flexible binder.

Table 1 also shows that there is no difference in the maximum thinning obtained by using either Mode 3 or Mode 4 trajectories. This apparent insensitivity to pin-force variation with stroke may be due to the inherent constraint/assumptions used in the optimization procedures.

Table 1. Effect of trajectory mode on maximum thinning in the simulated liftgate.

Trajectory Mode	Description	Maximum Thinning (%)
Mode 1	Pin forces constant in space and stroke	27
Mode 2	Pin forces constant in space and variable in stroke	25
Mode 3	Pin forces variable in space and constant in stroke	23
Mode 4	Pin forces variable in space and stroke	23

Predicted optimized binder-force trajectories for Mode 3, variable in space but constant during the stroke, for A6111-T4, BH210 and DP500 are shown in Figure 3. It is interesting to see that the trajectory patterns for the three materials are similar. They only differ in the level of force applied on each pin. This force level follows the same pattern followed by the yield/tensile strength of those materials.

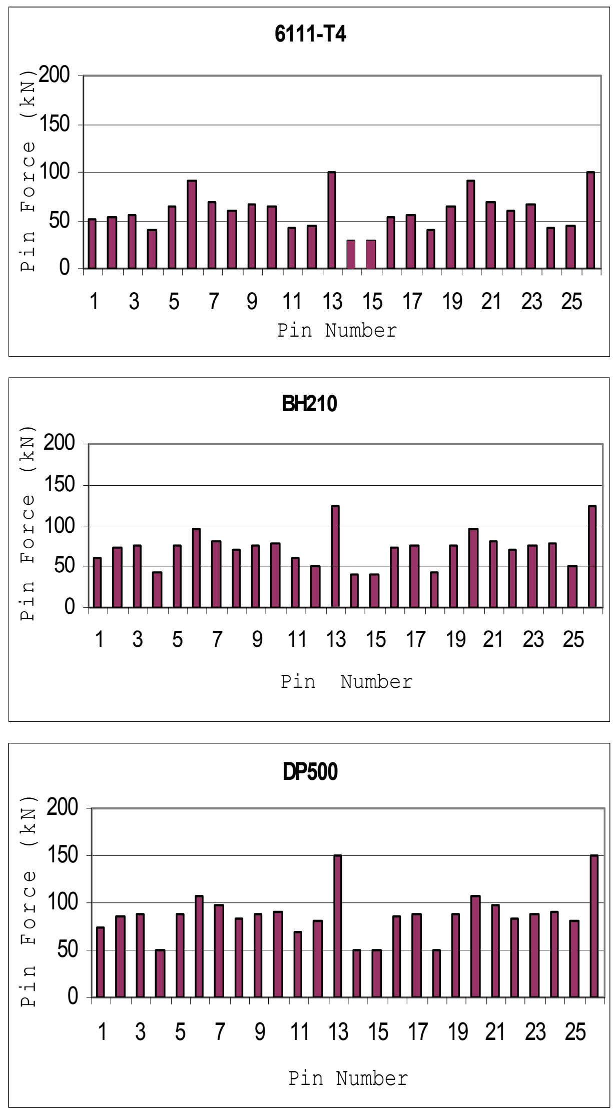

Figure 3. Predicted binder-force trajectories, variable in space but constant in stroke, for A6111-T4, BH210 and DP500.

Figure 4 shows two sets of predicted trajectories for A6111-T4 using the Mode 4 scheme. Set 1 was obtained using sequential optimization while set 2 resulted from using fixed-curve-shape optimization. The trajectories in set 1 start low and end up high while trajectories in set 2 start high, reach a minimum at a stroke of 40 mm, then increase gradually until the end of the stroke.

Set 1 produced panels with two splits in the window area that were corrected later by increasing pin forces in that location. Set 2 produced panels with splits above the liftgate window. No tryouts to fix those splits were attempted.

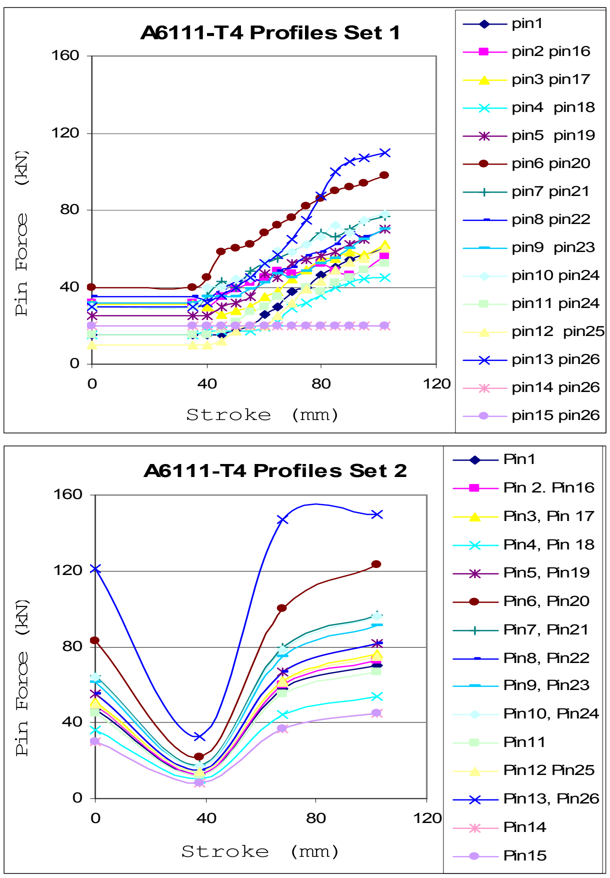

Figure 4. Predicted binder-force trajectories, variable in space and stroke, for A6111-T4.

Liftgate Tryouts and Demonstration

The 26-point, flexible-binder control unit with the liftgate tooling was installed in a mechanical press at Troy Design and Manufacturing (TDM) in Warren, Michigan and tested using both constant and variable binder-force trajectories. Liftgate panels were successfully made from BH210, DP500 and A6111-T4 using the same set of tools.

Figure 5 shows an A6111-T4 blank geometry of 1 mm thickness used in the experiments/tryout. The edges of the blanks were deburred to avoid cracking during forming due to defects in blanking and piercing from the coil. The sheets were lubricated with dry thin-film lubricant precoated on the coil from the rolling mill.

Figure 5. Blank from A6111-T4 used in tryouts.

The tryout time using the system was less than the estimated tryout time using conventional methods of working the die. Splits could literally be eliminated in minutes by adjusting the tonnages of the appropriate cylinders.

Binder-force estimates from FEA were used for the initial tryout of A6111-T4. The liftgate panels were formed without splits (Figure 6). However, minor wrinkles were observed in the flange area beyond the drawbeads on the top and bottom and on one of the corners. Experiments carried out with very high binder force could not eliminate the wrinkles in the flange as observed in FEM simulation.

Figure 7 shows liftgate panels made from three materials: A6111-T4 (top), BH210 (middle) and DP500 (bottom).

Figure 6. Panels from using Mode 4 trajectory.

Figure 7. Liftgate panels made from A6111-T4, BH210 and DP500.

The A6111-T4 panels were made with Mode 3 and Mode 4 trajectories. Mode 3 trajectory formed the panel without splits on the first hit. Mode 4 trajectory formed the panel with splits (Figure 8 top) that were later eliminated by increasing force on specific pins in the last 12 mm of the stroke (Figure 8 bottom). BH210 panels were made with Mode 3 trajectory without any splits. DP500 panels were made using Mode 3 trajectory with splits in the window area that were later eliminated by using trial-and-error to setup appropriate pin-force trajectories.

Figure 8. A6111-T4 liftgate panels formed with splits (top) and without splits (bottom).

Reproducibility tests were performed to evaluate the ability of the flexible-binder system to produce identical panels in consecutive hits. Ten panels were formed in sequence using the same binder-load trajectory and then checked for dimensional accuracy and thinning. Results indicated that the stamping process produced consistent panels.

Room-Temperature Forming of Mg Alloys

The use of sheet Mg alloys for auto-body applications is very limited because their room-temperature formabilities are low. Currently, Mg alloys can only be formed at elevated temperatures.

However, the introduction of new Mg sheet alloys AZ31B and ZK10 with improved room-temperature formability as well as the development of new methods for processing and stamping sheet metal, made it interesting to re-evaluate such alloys for room-temperature forming via flexible-binder control.

A. Viscous Pressure Bulge (VPB) Test of Mg Alloys

One of the objectives of this study is to conduct VPB tests on 1.3-mm-thick Mg sheet alloy AZ31B and 1.2-mm-thick Mg sheet alloy ZK10 to determine their room-temperature flow stress and formability. A schematic drawing for the VPB tooling is shown in Figure 9.

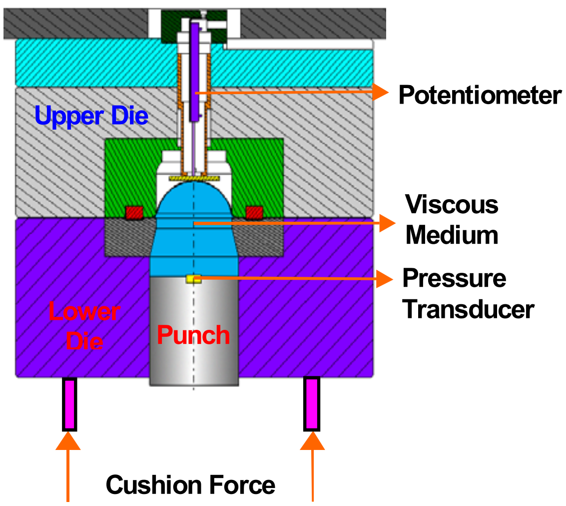

Figure 9. Schematic of the viscous pressure bulge (VPB) test.

In the VPB test, the pressure and the dome height would be used to estimate the flow stress of the material using inverse analysis. The dome height before the burst indicates the formability of the material. Five samples would be tested to check for consistency in the values obtained for flow stress and formability.

The first step in conducting the test is to clamp the sheet metal between the upper and the lower die. Doing this step with Mg alloys proved to be challenging. The sheet metal failed by brittle fracture at the lockbead location because the radius of the lockbead was too small for bending the material. Figure 10 shows a AZ31B blank after being clamped.

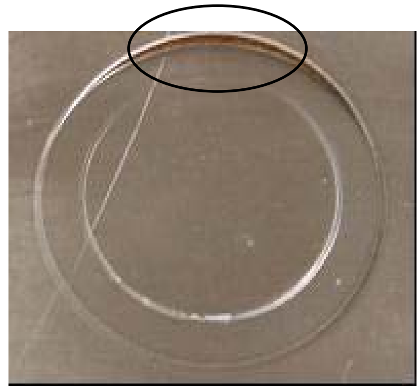

Figure 10. Brittle fracture at the lockbead location during the VPB test for AZ31B.

Because the lockbead in the tooling caused brittle fracture of the material in the test setup, it was later removed and the test was performed using a blank holder force of 500 kN. Figure 11 shows Mg sheet formed in the VPB test without using lockbead. This time, the sample failed due to brittle fracture at the die radius thus producing a very small dome height. This indicates that a die radius of 6.25 mm was just too small for successful bending of the Mg-alloy sheet material AZ31B.

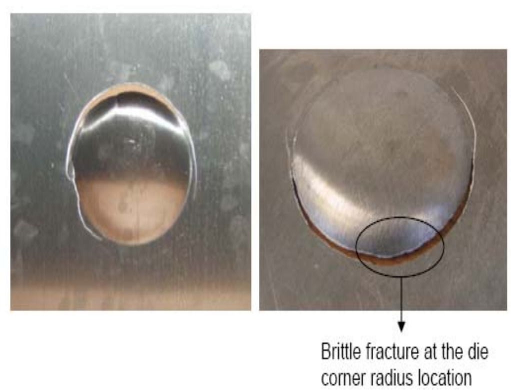

Figure 11. Magnesium alloy AZ31B formed in the VPB test without using lockbead.

To overcome the problem caused by the small die radius, another VPB test setup with a larger die radius of 30.4 mm and without lockbead was used. This time the magnesium sheet fractured at a dome height of ~13 mm.

Maximum achievable strain for Mg-alloy AZ31B, electrically-treated AZ31B and ZK10 was 0.05, 0.065 and 0.08, respectively, due to their small dome heights. A comparison of the dome height obtained from the test for different materials is shown in Figure 12. The results show that the dome height of magnesium alloys AZ31B and ZK10 are significantly lower than those for BH210, A6111-T4 and DP500, in spite of the fact that the die radius used for these materials was much smaller than that used for the Mg alloys.

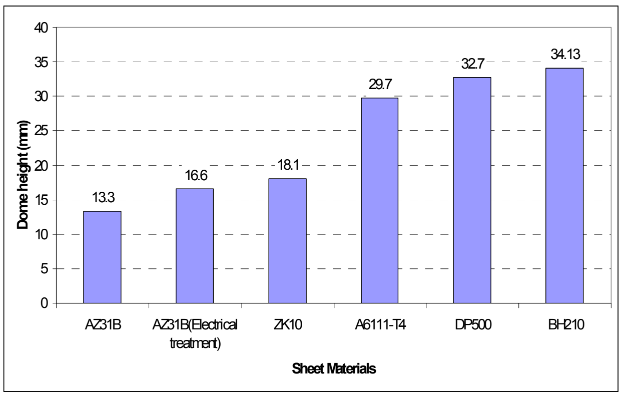

Figure 12. Comparison of the dome height obtained in VPB test for sheet materials A6111-T4, BH210, DP500, ZK10 and AZ31B.

The figure also shows that the maximum dome height before failure for AZ31B, electrically-treated AZ31B and ZK10 material was 13.3 mm, 16.6 mm and 18.1 mm, respectively, indicating very low formability for these materials at room temperature. Although electrical treatment for AZ31B improved its formability by increasing the dome height from 13.3 mm to 16.6 mm, it is still considered to be low in comparison to the dome heights of steel and Al alloy.

Figure 13 shows photos of the burst samples in the VPB test for A6111-T4, BH210, DP500 AZ31B and ZK10. Superimposed on the photos are measurements of the dome heights. The Mg alloys showed poor formability in spite of removing the drawbeads and using a larger die corner radius of 30.2 mm.

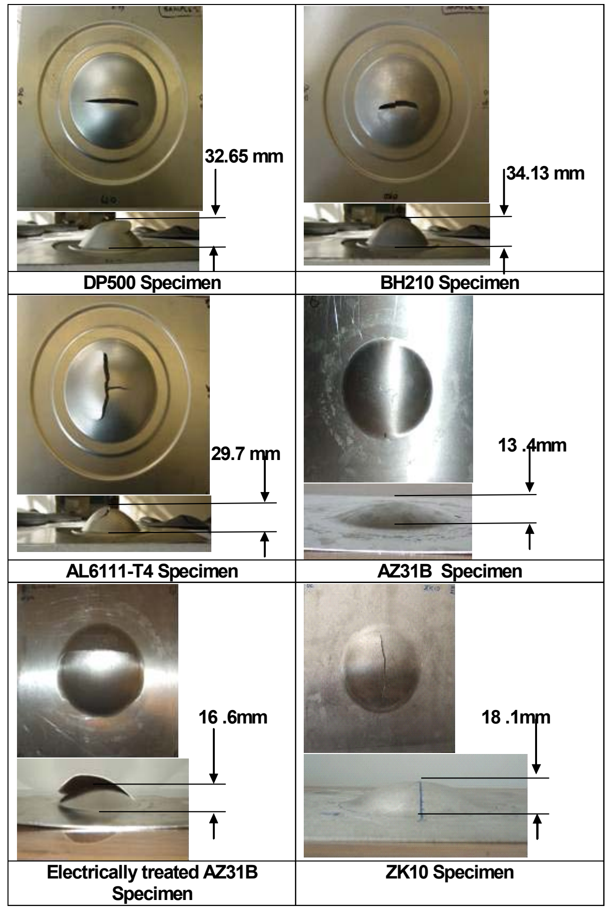

Figure 13. Comparison of the burst samples in VPB test at room temperature from sheet materials A6111-T4, BH210, DP500, AZ31B and ZK10.

B. Simulation of the VPB Test for Mg Alloys

The critical value of the effective strain that would result in brittle fracture of the AZ31B sheet material during bending was estimated from the VPB test. The maximum effective strain in the material at the fracture location could not be measured. Therefore, FE simulation of the test was conducted to predict the effective strain at the fracture location observed in the test. The maximum effective strain predicted by FE simulation for the dome height of 13.8 mm and forming pressure of 43 bars occurred at the die radius where fracture was observed in the experiment. The maximum strain due to stretching and bending at that location was 0.05. This value of strain would be used as a failure criterion for predicting brittle fracture during bending of AZ31B sheet material. The failure criterion was later used to check the feasibility of forming liftgate panels from the Mg alloy.

C. Simulation of the Mg Liftgate

The liftgate tooling was selected to check the possibility of forming sheet AZ31B at room temperature using the multi-point cushion system developed in this program. The same liftgate tool was used in the past to successfully stamp panels from A6111-T4, BH210 and DP500 sheet material.

FE simulation coupled with optimization was used to estimate the optimum binder-force trajectories needed to form the GM liftgate part from sheet AZ31B. The flow stress of the material was estimated from the VPB test and used as input for the FE simulation.

During the clamping stage of the forming simulation, the sheet metal bends and unbends at the upper and lower bead as shown in Figure 14. The bending deformation of the sheet metal is similar to that observed at the die radius in the VPB test where brittle fracture occurred. Therefore, in order to check for potential brittle fracture of the sheet metal at the location of bending in the liftgate drawbead, the predicted maximum effective strain at that location was compared with the critical value of 0.05 obtained from VPB test for the AZ31B.

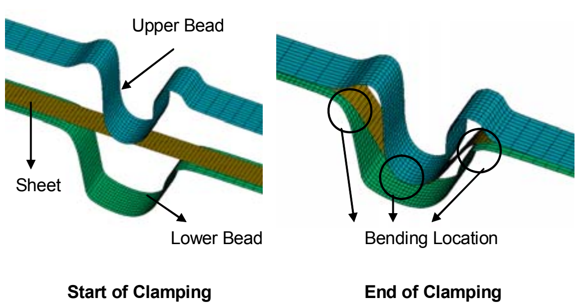

Figure 14. Drawbead simulation of the sheet at the start and end of the clamping.

In drawbeads, bending deformation is observed at three locations as shown in Figure 15. The predicted maximum effective strain in the drawbead was higher than the estimated critical value indicating potential failure of the sheet metal at the drawbead when the sheet is clamped.

Figure 15 simply suggests that the liftgate part would fail at the clamping stage and, therefore, the liftgate panel could not be formed from AZ31B sheet material at room temperature using the existing tooling.

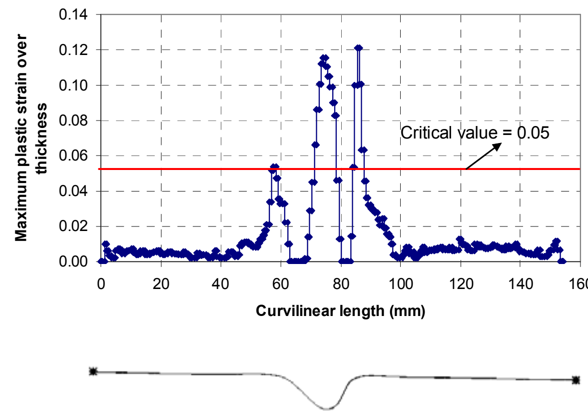

Figure 15. Maximum effective strain along the curvilinear length of the sheet at the end of clamping.

Because FE simulation predicted failure of the liftgate at the clamping stage, forming simulation of the part beyond clamping was found to be futile and, therefore, was not pursued. It was then decided to try forming the liftgate panel using die tryouts at TDM.

D. Tryouts on the Mg Liftgate

Several attempts were made to form liftgate parts from AZ31. Initially, based on FEA simulations, the tonnage in all cylinders was set to 5.1 tons. However, the material fractured upon bead set as seen in Figure 16. It is also noted that the fractures upon bead set in the tryouts were predicted by FEA analysis and also observed in biaxial tests. Following this tryout, another attempt was made to form the part with tonnages reduced to 1 ton through the stroke for all cylinders. In addition, the 404 lubricant typically used for Al was applied to the blank and the ram was set to cycle to 25 mm (1 in) off the bottom of the stroke. The outcome of this tryout was similar to the previous attempt.

Forming liftgate panels from these versions of magnesium alloys AZ31B and ZK10 at room temperature is not feasible. The alloys performed poorly in situations where sharp bends were involved. Although the formability of Mg alloys at room temperature is low compared to Al and steel, it may still be possible to stamp such materials into

Figure 16. Magnesium AZ31 liftgate trial with 404 lubricant and minimum tonnage.

simple shapes using flat binders. The application of an electric field during annealing of Mg alloys appears to increase their forming properties. The increase, however, is not sufficient to make Mg alloys formable at room temperature.

Pan Tryouts and IFU Unit Demonstration

A new 10-cylinder, binder-load control unit with pan tooling was built in Germany by a consortium which included the University of Stuttgart (IFU), MOOG, Hydac and the USCAR. The unit was tested successfully in a hydraulic press at the University of Stuttgart in Germany. The unit was shipped to the US in November 2005 for installation tryouts and demonstration in a mechanical press at the TDM facility in Warren, Michigan.

A. Control System Tests

IFU, with technical support from Hydac and Moog, ran tests to verify that the pressure control system can track all command trajectories. Figure 17 shows an example of a flawless tracking force-versus-stroke trajectory in cylinder #5 at a slide velocity of 300 mm/s. The actual value and the command signal for a rectangular force/stroke profile were almost identical.

Figure 17. Force-versus-stroke trajectory.

B. Closed-loop Tests

IFU and its partners performed tests on closed-loop control using wrinkle-height sensors. The tests were run with and without closed-loop control to show that the IFU unit can actually modulate the binder force in-process to produce wrinkle-free pans. The first set of tests was performed in Stuttgart using IFU's hydraulic press with a slide velocity of 20 mm/s. The test was initially run without activation of the closed-loop control system with the wrinkle-height sensor.

To produce wrinkles in a mild steel pan, a small binder force of 6 kN was applied to each of the six activated cylinders. This situation produced wrinkles so high (over 10 mm) that the drawing process had to be stopped at a depth of 100 mm for fear of damaging the die. In the second set of experiments, the 6 kN load was maintained on the six active cylinders, but this time the closed-loop control system was activated. A small, constant, wrinkle-height value of 6 mm was set as a limiting wrinkle height that should not be exceeded. The controller was successful in maintaining the imposed limit by modulating the binderforce on the six cylinders. Figures 18 and 19 clearly show that closed-loop control produces a significant improvement in the quality of the drawn pan.

Figure 18. Pan drawn without closed-loop control.

Figure 19. Pan drawn with closed-loop control.

A week-long demonstration of this technology was conducted on the IFU unit for project members, OEM personnel, DOE partners, suppliers, contractors, educators and students. The demonstration was intended to show the capabilities of flexible-binder technology and the benefits of using closed-loop control in the stamping process.

Wheelhouse Demonstration

The binder-load control unit was modified to accommodate the wheelhouse die to perform tryouts to evaluate the following:

- Springback Control
- Production Casting Flexibility
- Alternate Material Tryout
- Impact Tonnage Reduction
- Reduced Material Usage

The wheelhouse die, shown in Figure 20, was donated by Ford Motor Company. It was taken out of production because the high-impact tonnage requirements caused damage to the stamping press.

Figure 20. Wheelhouse die.

Tests were conducted on production steel, BH, DP, and Al materials. Two trajectories were used, one with constant tonnage during stroke and the other with variable tonnage during stroke. Reduced-blank-size panels were also used. Parts were laser trimmed then scanned for comparisons using a current production draw panel as a reference material. The current rigid binder design was used for testing and single-cylinder pressure adjustments were made to show the ability of the binder to flex. Tryouts were conducted to show the capability of the binder-control unit to influence panel quality by creating or relieving fractures in the stamped part.

Test Results

- Proved the ability to influence part springback and splits through cylinder pressure adjustments.
- Proved flexibility of current production binder and its compatibility with variable- pressure technology.
- All tryout were completed without the use of “stand off’’ blocks on binder.
- Showed the ability to try out different materials and thicknesses by changing trajectories and without die hand work.
- Showed ability to reduce number of hits to achieve panels from difficult-to-form sheets.
- Reduced the impact tonnage from 274 tons with constant-stroke trajectory to 182 tons with variable-stroke trajectory.

- Test panels showed excessive springback with full blank but improved greatly with reduced blank panel with variable-stroke trajectory.
- Reduced blank weight by 15% and produced production-worthy stamping from production and BH materials using variable-pressure trajectories (Figure 21).
- Scans showed improved springback for reduced-size blanks that ran with variable trajectories.

Figure 21. Successful wheelhouse part with reduced production blank.

Technology Value

The ability to influence metal flow by simply changing pressure settings on individual cylinders very quickly replaced an estimated 4-8 hours of die work which would have been required, with traditional binders, to correct stamping defects in formed panels.

The value of flexible-binder load-control technology can be assessed in terms of improving manufacturing capability and adding robustness to the production system. The following are some of the manufacturing benefits achieved using this technology:

- Reduce die tryout and development time
- Reduce time to tune/spot binder
- Compensate for tool wear by adjusting binder-force during production
- Reduce tool re-work during production
- Improve part quality by providing optimum load trajectories
- Change pressure with stroke
- Control springback
- Stamp difficult-to-form materials
- Reverse pressure settings using software (unlike grinding and welding)
- Reduce blank size and save materials

There is a need to quantify the cost savings associated with these manufacturing benefits.

Conclusions

1. A multi-point cushion system with 26 independently-controlled hydraulic cylinders was used to demonstrate flexible-binder control technology on a full-size automotive part.
2. The system reduced the die rework time by about 80%.
3. Splits and wrinkles could be eliminated or reduced in minutes by adjusting the tonnages of the appropriate cylinders in the system software.
4. The system enabled the stamping of liftgate panels from three different materials and thicknesses. This was accomplished by implementing appropriate binder-load trajectories for each material without the need to modify or adjust the stamping tools.
5. FE simulation coupled with optimization technique was used to predict binder-force trajectories using four trajectory patterns. Best results were obtained for trajectories varying in space and constant in stroke for all the liftgate materials. Trajectories that vary in both space and time were not successful in producing defect free panels.
6. The demonstrations showed that FEA-based optimization can provide effective initial settings for tonnages and these settings can be easily modified to obtain good parts.
7. The capabilities of a 10-cylinder binder-load control unit with pan tooling and advanced controls was demonstrated at TDM.
8. Closed-loop tests show clearly that feedback control can produce a significant improvement in the quality of the pan.
9. System improved springback, reduced impact load and allowed the downsizing of blank.
10. Manufacturing benefits, value of technology and its implementation were reviewed.

Presentations and Publications

1. **Application of Flexible-binder Technology for Stamping of Liftgate Panels:**

Mahmoud Y. Demeri, Formsys Inc.
Presentation and publication at the International Conference on "New Developments in Sheet Metal Forming", Stuttgart, Germany, May 9-10, 2006.

2. **Robust Deep Drawing Process of Extensive Car Body Panels:**
   J. Hengelhaupt, M. Vulcan, IFU
   P. Ganz and R. Schweizer, MOOG
   F. Darm, Hydac
   Presentation and publication at the International Conference on "New Developments in Sheet Metal Forming", Stuttgart, Germany, May 9-10, 2006.

3. **Programming of Multi-Point Cushion Systems – Progress and Future:**
   T. Altan and M. S. H. Palaniswamy, OSU
   Presentation and publication at the International Conference on "New Developments in Sheet Metal Forming", Stuttgart, Germany, May 9-10, 2006.

4. **Project Presentations:**
   AMD Offsite Meeting, USCAR, October 27, 2005.

5. **Innovation in Stamping Technology:**
   M. Y. Demeri, Formsys Inc.
   Presentation at the International Congress TRANSFAC '06, San Sebastian, Spain October 4-6, 2006.

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[i] Denotes project 301 of the Automotive Metals Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development.