Intelligent Computer-Aided Stamping System (ICASS)

Maximizing Productivity Using Variable Binder Force Technology
Summary: Sheet metal stamping is a manufacturing process that is widely used in several industries. Examples of stamped metal parts are doors and hoods of automobiles, domestic appliance housings, and kitchen sinks. However, the design and construction of dies to make these parts without defects such as wrinkles and splits is a time consuming and labour intensive process, even today. In addition, operational variations such as lubricant build-up in the dies, small changes in the material properties and thicknesses of the sheet metal blanks as well as temperature effects can result in parts being formed with defects, thus resulting in material scrapping costs of millions of dollars. A new technology that involves a computerized system to accurately control the forces holding the sheet of metal at various points in order to eliminate these defects has been developed based on extensive research of the last 20 years. These systems are now available for shop-floor use as Intelligent Computer Aided Stamping Systems (ICASS) developed by Intellicass Inc. The use of these systems can result in material savings of around $1000/hour in a typical stamping plant making car door-sized parts from lightweight hard-to-form materials such as aluminum.

Introduction: The process of sheet-metal stamping is one the most efficient and widely used metal forming processes in manufacturing. It is used to form sheet-metal parts in several industries, ranging from doors and hoods in automobiles to housings in washing machines, and even kitchen sinks. The process of sheet-metal stamping (or drawing) involves placing a sheet of metal (the blank) between an upper and a lower die, which are cut in the form of the desired part and are geometric negatives of each other, and driving the upper die (or punch) into the lower die with high force using a press. The sheet of metal is held between a blank-holder (also known as a binder) which runs around the die, as shown in Figure 1, and is stamped into the desired shape by the press.

![Figure 1: Schematic of sheet metal stamping](image_url)

Die design is a complex task, as forming dynamics involve interactions between the sheet-metal blank, the press, the blank-holder, and the die. In addition, operating conditions such as die lubrication and temperature significantly affect the forming process. Typical defects that occur due to incorrect flow of material into the die during the stamping process are wrinkling (caused by excessive compression),
tearing or splitting (caused by excessive tension), and springback (caused by elastic recovery of the metal), as shown in Figure 2.

![Figure 2: Typical defects in stamped parts](image)

Traditional stamping involves using a constant and uniform blank-holder (or binder) force and shaping a drawbead (see Figure 1) on the blank-holder to control the rate of material flow into the die. This is a passive method, and cutting the appropriate drawbead on the binder requires extensive computer simulations based on Finite Element Analysis (FEA), as well as trial-and-error based grinding or welding. If the drawbead geometry is incorrect, the blank will not be drawn into the die correctly, and splits and/or wrinkles will occur. Thus, die try-out, the process in which the die and drawbead geometry are worked by grinding and welding to correct forming defects (see Figure 3), is very time consuming and labour intensive. In addition, even when a drawbead is cut correctly for nominal conditions (blank thickness, die lubrication etc.), part defects can occur when these conditions change (for example, a small change in blank thickness in material from different suppliers, or lubrication build-up in the die after a few thousand parts are run), resulting in high scrap rates.

![Figure 3: Die-work during try-out to correct stamped part defects](image)
Die-design and try-out problems are compounded with the use of light-weight/high-strength alloys for making stamped parts. Significantly higher fuel efficiency and safety standards in the automotive industry are necessitating the use of such materials, and coupled with a highly competitive business environment, there is an urgent need to improve the efficiency of both the die-making and stamping processes.

**Variable Binder Force Control:** The use of locally varying binder force to eliminate stamped part defects and improve formability has been extensively studied in the academic research community over the last twenty years [1-24]. The idea of using variable binder force is conceptually simple: if a split is imminent, the binder force near the location of the split is reduced, thus reducing the tension on the blank and preventing the split; conversely, if a wrinkle is starting to form, the binder force is increased, thus increasing the tension in the blank and stretching out the wrinkle. However, since the stamping cycle is relatively quick (typically 0.5 – 0.8 sec), and the timing of the force adjustment is critical, implementing such a system to precisely adjust the appropriate binder force at multiple locations around the blank presents several engineering and technological challenges. Thus, a large number of studies have relied on simulation to validate the concept; however, there have been some experimental studies using simple part geometries (cups or pans) with hydraulic presses which drive the punch at a constant speed (see [4, 5, 9, 13, 14, 24, 25, 31], for example). However, more recent work conducted by the University of Michigan and Intellicass in partnership with Troy Design and Manufacturing (a wholly owned subsidiary of the Ford Motor Company) ([32-34]) has shown that variable binder force control can significantly improve the efficiency of die try-out. It can also maintain part consistency in the presence of operational variations, even for typical automotive parts with deep draws and complex geometries, while using standard mechanical presses designed for high-volume production. Figure 4 shows a typical result where simultaneously occurring splits and wrinkles are eliminated using variable binder force control on a part made with a tailor-welded blank.

![Figure 4: Wrinkle and split corrected using variable binder force](image-url)
Technological Challenges in Developing Variable Binder Force Systems:

1. Design for Mechanical Presses: Hydraulic binder force control systems (also known as programmable multi-point cushion systems) consist of hydraulic cylinders that deliver the required force to the appropriate location on the binder. The hydraulic fluid in the cylinder is compressed by the downward motion of the press ram, and the fluid is metered out through a servovalve that is controlled by a real-time computer system (see Figure 5). Most programmable hydraulic cushions are designed for hydraulic presses, which have relatively constant ram speeds, thus allowing relatively simple logic-based or PID control algorithms to be effective. However, in a mechanical press that is typically used for fast, high-volume production, the ram speed is high at the top of the stamping cycle and zero at the bottom because of the use of a crank drive. This non-constant ram speed profile necessitates a much more sophisticated control algorithm to regulate the fluid flow out of the cylinder to generate the desired binder force. The Intellicass ICASS uses a patented control algorithm to achieve accurate hydraulic binder force control in both hydraulic and mechanical presses operating at a range of ram speeds.

![Figure 5: Schematic of hydraulic binder-force control system](image)

2. Cost-effective reconfigurable design for try-out: The key to effective use of variable binder-force technology is being able to determine the required binder force profiles during try-out. Production facilities do not want to waste time and man-power on determining optimal binder forces. Thus, both die-construction/try-out and production facilities need to have access to cost-effective variable binder-force systems. Currently, most programmable cushions, which only have limited spatial and time-based control, are prohibitively expensive for try-out facilities, and are only found in top-of-the-line presses in production. However, they are rarely used effectively in production because production facilities do not have the resources to determine the required
binder force trajectories. By developing a cost-effective reconfigurable solution that can be used effectively for any die in any press for try-out, and a complementary system for production, ICASS provides the means to exploit this technology.

Figure 6: ICASS for try-out

ICASS in Try-Out: ICASS has been extensively used in try-out for more than 3 years at Troy Design and Manufacturing, with several hundreds of parts produced for prototype vehicles. It has been particularly helpful to rapidly address defects in hard-to-form parts using tailor-welded blanks (Figure 4) and lightweight materials such as aluminum. Using the system, try-out time has been reduced 60 – 80% depending on the part. In Figure 7, the bottom of an aluminum door-inner is shown, with (a) showing the part made using conventional FEA-based methods and (b) showing the part made using ICASS. In addition to very effectively reducing wrinkling, it can be seen that ICASS leaves more material outside the drawbead line, which can be cut from the blank for material saving (as indicated by the dashed yellow line). Any wrinkling caused by reducing the blank size can be corrected by locally increasing the binder forces at the bottom of the stroke using ICASS.
ICASS in Production: Besides the obvious requirement that variable binder-force usage in try-out would necessitate the same capability in production, analysis shows that using variable binder-force technology in production results in very high levels of cost-savings. Specifically, cost savings stem from:

1. Smaller blank size as detailed in the previous section
2. Reduced scrap when using automatic tonnage correction for lube build-up and for operational variations
3. Reduced material tolerance requirements because of a more robust stamping process
4. Reduced down-time to correct for defects
5. Reduced maintenance costs due to lower press impact forces (the binder tonnages are built up from near zero in about 0.1 sec)
6. Virtual elimination of panel bounce due to smooth return of the binder under controlled hydraulic pressure
7. Capability that exceeds that of the most expensive programmable cushions built by large press manufacturers at a fraction of the cost provides a strong competitive advantage, leading to more business

Cost savings from (1) and (2) alone are estimated at more than $1,000/hour for an aluminum part the size of a door-inner running in a tandem line operating at 10 strokes/min.

The key technology for reducing scrap and enabling a more robust production run is the use of process control for stamping. This concept has also been actively studied in academia [27 – 42] and is based on using real-time feedback of a quantity that provides information on part quality and consistency, such as
material draw-in, punch force or friction force, to actively adjust the binder forces to compensate for operational variations such as lubrication build-up in the die, or small changes in sheet metal material properties. Several academic publications have validated this concept using simple part geometries and hydraulic presses [25 – 31]. A significant amount of research has also been conducted on development of sensors for real-time feedback [35 – 40]. However, technology jointly developed by Intelliclass and the University of Michigan utilizes existing tonnage monitors to provide total press-force feedback for process control, and has been tested at two facilities, namely Troy Design and Manufacturing (for try-out/prototype) and Ogihara America Corporation (for production). Figure 8 shows a graphical representation of process control using tonnage monitor feedback, while Figure 9 shows tonnage monitor readings that capture operational variations, thus demonstrating that these readings can be used to adjust binder forces and reduce the scrap rate.

Figure 8: Process control schematic

![Process control schematic](image)

Figure 9: Tonnage monitor data capturing operational variations for process control feedback

![Tonnage monitor data](image)
Figure 10 shows wrinkles caused by excessive lubrication (a) automatically corrected using process control (b).

**Figure 10**: Wrinkles caused by excessive lubrication (a) and corrected by process control with variable binder force (b)

**Cost-savings Estimate**: The estimate given below is based on a production run of door-sized panel made from draw quality aluminum. The assumptions are as follows:

1. Press tandem line runs at 10 strokes/minute, or production of 600 parts/hour
2. Differential between cost and scrap recovery rate per blank is $35
3. Current scrap rate is 8%

From test data, it is estimated that the use of ICASS results in material savings from blank size reduction of 2% and scrap reduction from 8% to 4% with process control. Thus, total **material savings of 6%** are achieved or in dollar terms = 0.06 x $35/part x 600 parts/hour = **$1080/hour**.

Other benefits include reduced try-out time for launching dies, reduced down-time for die work, lower press maintenance costs, and lower costs for production delays. With a utilization of 1000 hours/year, each ICASS in production **generates savings** of more than **$1 million per year**.

For try-out, ICASS significantly reduces the time required for die work. In one test case, a good part was produced using ICASS with 2 man-hours of effort. The die was then worked based on material flow information obtained from deploying ICASS, and it took 32 man-hours to get a comparable part using traditional methods. Thus, a reduction of 93% in try-out time was realized. However, on an average, try-out time is reduced by 60 – 80% with ICASS.

Furthermore, FEA simulation time can be reduced, as a basic drawbead design can be enhanced using variable binder force control. Thus, extensive simulation to design precisely engineered drawbeads is not required. Combining FEA simulation time savings with reduced try-out time leads to faster time to production.
Conclusion: The sheet metal stamping process can be significantly enhanced by the use of variable binder force technology, specifically by generating material savings in production and reducing try-out time. The technology has been the subject of extensive academic research and has now been transitioned to shop-floor use by Intellicass. The potential for cost-saving using these systems is very high (estimated at around $1000/hour for a typical automotive application). The technology can be non-disruptive and can be easily integrated into existing facilities, and is expected to be transformative in the world of sheet metal stamping.

References


