

Reducing Stamped Part Development Time with Pulsed Energy Assistance

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The Problem

Presently one of the most serious time delays between bringing an automobile from design concept to manufacture is the process of designing a metal forming die, fabricating a try out die, testing the try-out die, iteratively modifying it until it performs well and finally fabricating a production die. This die try-out process can take up to twelve months alone. The increasing reliability and reliance on finite element analysis has improved this situation, but as the industry makes increasing use of 'advanced' materials such as high strength steels and aluminum the difficulty in forming these materials with appropriate dimensional tolerances will diminish the gains made by FEM.

Here we make the case that by doing the forming operation in a fundamentally different way we can increase the degrees of freedom on the forming process, thereby allowing one to tune forming characteristics without modifying dies or making multiple tools.

Another Approach

Over the past several years work in our group has shown metals can be stretched to much higher strains at high velocity versus conventional quasi-static stretching. We refer to this extended ductility in high velocity conditions as hyperplasticity. We have worked in both understanding formability in a fundamental way and applying this to practical sheet metal forming. One of the most attractive ways of developing high velocity metal forming is with electromagnetic forming. Electromagnetic forming actuators can be fabricated into a wide variety of

configurations and used in conjunction with stamping operations. We believe the end result of this vision will be that many sheet metal components will be able to be fabricated with a smaller number of operations (i.e., fewer press stands) and that it will enable the fabrication of many components from difficult materials such as aluminum.

The Technology

Current production methods of forming sheet metal into auto body panels are slow enough that inertial forces within the sheet are truly negligible. This condition simplifies many aspects of the processes including tooling, press design and process analysis. However, it has been known for many years that when plastic deformation of a ductile sheet metal takes place at high velocity, when stresses due to inertial forces are significant, greater limit strains are obtainable [1, 2]. Experimental and analytic evidence from several sources indicate that limit strains are extended largely due to the inertial suppression of localized necking [3,4,5]. Aluminum alloys respond particularly well and are notable due to their emerging importance to the automotive market. Candidate sheet metals are not limited to the aluminum alloys but also include low carbon steels that are heavily cold worked to high yield strengths. These steels exhibit quasi-static, uniaxial limit strains of less than 5%. However, recent experiments demonstrated that these same steels, under high velocity impact forming can show useful strains in excess of 30%.

Directly generating sheet deformation velocities of 50 - 300 m/sec is not practical or even possible using conventional stamping tools and presses for any auto body panel parts of common size. A fundamentally different energy delivery means is required. The first successful processes used explosive charges positioned over the work and submerged in a tank of water. The aerospace industry continues to produce complex auto body scale parts in this manner. Submerged electric arc discharges develop explosive-like pulses sufficient to perform high velocity sheet metal forming can be readily generated with a high voltage transformer, a storage capacitor and a fast acting switch. Such machines were commercially developed and employed during the sixties and seventies within the aerospace industry. For various

reasons, these machines never took root in other industries.

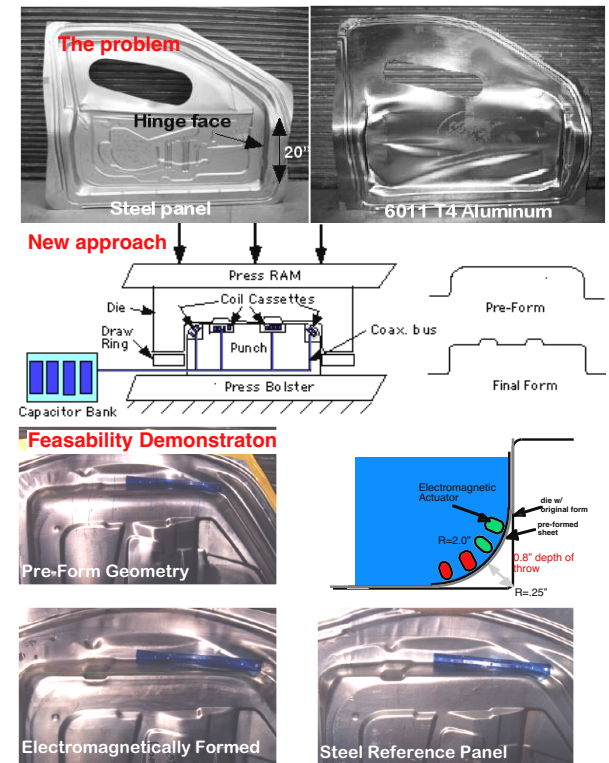


Figure 1. Use of EMAS to solve one particular problem. Despite substantial weight savings, aluminum has insufficient formability to form door inner panels using conventional stamping as illustrated by the torn and wrinkled aluminum blanks that result when conventional stamping is used (top). The hybrid electromagnetic assisted stamping process is illustrated in the middle sketch. At the bottom the successful demonstration of this approach to enable the formation of door inner hinge faces using EMAS is illustrated. This demonstration was carried out at Ohio State with funding and substantial participation from GM, Ford and Chrysler.

A closely related, electromagnetic variation of the submerged arc machines has found limited industrial application. Capacitor bank machines for pulsed electromagnetic metal (PEM) forming processes have been commercially available for decades although largely restricted to clinch assembly and swaging applications. To completely form a common size auto body panel by PEM alone would require quite a large capacitor-coil system

with very significant complications in the design [6] problems. Integrating PEM forming with conventional stamping methods resolves the conflict between enhanced forming performance of PEM and the system design issues of up-scaling a PEM process. The viability of such a hybrid sheet metal stamping process, referred to as the Matched tool-electromagnetic (MT-EM) process also known as Electromagnetic Assisted Stamping (EMAS) been demonstrated as show in Figure 1 [7]. The essential attributes of the hybrid process are that the majority of the forming is done conventionally with the PEM process only applied locally, to the difficult geometry regions of the part. The difficult areas are washed out of the conventional forming tool and then added back by the PEM method. Optimally the PEM process takes place within the primary press forming cycle but can be as a secondary operation.

Variations

PEM forming events generally require discharge levels which can produce magnetic pressure, due to the Lorenz forces, which are significantly in excess of the flow strength of the work piece metal. The localization inherent in the hybrid MT-EM process keeps the total PEM energy requirements within manageable levels. However, a lower energy variation of the MT-EM process is bump forming. In the bump forming variation, the PEM event does not perform the final forming of a local geometry but provides a distributed magnetic pressure along the punch nose radii. The electromagnetic driver coils for bump forming are designed to generate magnetic pressures sufficient only to stretch the work piece a few percent which results in a virtual elimination of friction between the form tool and work piece. Reduction of the high contact pressures by PEM discharges, applied several times during the forming stroke of the press, provides a means to better distribute the plastic strains across the part metal on the punch face. This material would be effectively locked-out in a conventional operation and unavailable to the forming process. Pulse energy levels for bump forming will naturally vary with part geometry but can be estimated to be 5 to 30% of the levels required for significant PEM forming of parts with similar plans. However rather than a local hyperplastic effect, bump forming provides for the active redistribution of the plastic strains of a part to a more optimal extent than possible with the conventional matched tool process alone.

An added benefit of bump forming is that it is possible to control spring back in the final part form. If the conductors of a bump forming coil lie in close proximity to the punch nose radius and the part in this region is backed up by a die surface, then applying an energetic discharge at the bottom of the press stroke can result in significant through thickness, residual compressive stresses. Experiments at OSU have shown that with such coils and tools, spring back can be controlled by simply varying the discharge energy level.

The hybrid MT-EM process and the above variations have direct analogs in fluid pressure forming.

Added Processing Freedom

The fundamental concepts common to both hybrid processes are that the integration of localized high velocity forming into quasi-static conventional processes provides avenues of extended plasticity and active strain redistribution by which difficult stamped part geometries can be generated. These hybrid processes provide independent degrees of freedom with which to tailor the distribution, type and level of plastic strains during forming. The net effect of adding independent degrees of freedom to the conventional stamping process should be to reduce the development time to produce usable parts in addition to producing hitherto un-formable parts.

High Velocity Joining Technologies

Long standing manufacturing concerns of automakers involves problems of fastening as well as forming sheet metal parts. Spot welding, the most widely used method with steel parts, is significantly more difficult with aluminum. Spot clinching is an alternative to spot welding for a growing number of applications. Spot clinching is a much cleaner operation than spot welding and is more amenable to aluminum. In spot clinching the adjoining parts are held together by pushing a small diameter dimple into the overlaid pieces which is then flattened to form an interlocked area which resemble a rivet head. The forces required to form spot clinching can be quite high and therefore require much stronger machine structures and actuators than those required to apply contacts for spot welding. Consequently, conventional spot clinching is difficult to apply as far into the part(s) as commonly produced spot welds. Spot clinching is a capability of high velocity impact forming of small features and has been

demonstrated using projectiles fired from a compressed air gun. High velocity impact forming does not require hydraulic actuators or heavy frame structure and thus can extend the application of spot clinching to completely replace spot welds of comparable strength. Many different projectile materials can be used including various polymers and potentially, gelled liquids. Initial experiments have shown the potential of producing spot clinches of conventional quality or better. Component technologies currently exist to produce high velocity clinching units, which are both light and compact enough to be manipulated by the robot arms presently used for spot welding. Unlike PEM processes, high speed projectile clinching has no particular material dependency. Recent experimental results support applications extending to very low ductility steels.

Tube joining is an area of increased interest to the auto makers which parallels the increased use of hydro-formed tube parts. The chinch and swage assembly of tube like, closed form parts is one of the original applications of the PEM process. Much of the existing database of pulsed energy forming covers such applications and can profitably applied to the new tube joining problems.

- 1) *High Velocity Forming of Metals*, Revised Edition, E.L. Bruno, ed., ASTM, 1968
- 2) R. Davies and E. R. Austin, *Developments in High Speed Metal Forming*, Industrial Press, New York, 1970.
- 3) X. Hu and G.S. Daehn, *Acta Mater.*, **44**, pp 1021-33, 1996.
- 4) G. K Fenton and G. S. Daehn, *J. Mater. Proc. Tech.*, **75**, 6-16 (1998).
- 5) "Hyperplasticity-Increased Forming Limits at High Workpiece Velocities", V. S. Balanethiram and G. S. Daehn, *Scripta Metallurgica*, **31**, 515-520 (1994)
- 6) F.C. Moon, *Magneto-Solid Mechanics*, John Wiley and Sons Inc., 1984.
- 7) "A Hybrid Quasi-Static-Dynamic Process for Increased Limiting Strains in the Forming of Large Sheet Aluminum Parts", V. J. Vohnout, G. S. Daehn and R. Shivpuri, in *Advanced Technology of Plasticity, Proceedings of the 6th ICTP Conf.*, M. Geiger, Ed., pp. 1359-64 (1999)

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