Application of Electrohydraulic Forming for low volume and prototype parts

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Abstract

Electrohydraulic forming process enables forming of panels from Dual Phase steels in case the strain level required to fill the shape exceeds formability limit. Filling of the die cavity was conducted in nine discharges to allow for smoother materials flow from the flanges. Additional formability benefit was obtained by preforming operation which was based on bulging the areas of low strain adjacent to heavily stretched areas of the blank. Filling of all the radii was achieved during final higher energy discharges.

Keywords

Sheet metal forming, pulse, electrohydraulic.

1 Introduction

The trend of creating global vehicle architecture in automotive industry is broadly spreading among the automotive manufacturers. The need to create low cost prototype parts in order to satisfy the needs of prototype testing and shorten the new product launch timeline is very important for original equipment manufacturers. From this perspective, the processes using working media described in metal forming literature, for example by Lange (1985) instead of one of the tools (a punch or a die) are very attractive due to lower cost of the tool and elimination of the need for accurate alignment of matching tools helping to reduce product development cycle. In general, metal forming processes utilizing working media are commonly applied to deep drawing, stretch drawing and tubular parts expanding.

Quasistatic processes are easier to analyze, experiment with and develop design guidelines because the general considerations are very similar to those used in traditional stamping on the press. A general disadvantage of these processes is in necessity to apply the pressure necessary to form the smallest radii cavity to the whole blank. This circumstance requires very large capital investments to implement these technologies. Nevertheless the need to form the prototype parts motivated rather broad implementation of hydroforming processes using polyurethane membrane to separate sheet metal blank from the fluid known, according to Altan and Tekkaya (2012) as flexform presses. These processes are often called crush forming, since no binder is being used to control material inflow into the die cavity. The high velocity forming processes were attempted to be used in industry in 1960s described by Bruno (1968) and in early 1970s described by Davies and Austin due to a number of substantial advantages which they offer. The most critical was the ability to form large parts with dimensions in the range of several meters which was impossible during the time of early studies.

2 Literature review

Hanley (1962) performed a comprehensive review of studies of application of all high velocity forming methods at General Dynamics: EHF was viewed as the most efficient method for expansion of tubular blanks with possible piercing of holes in the same tool. The diameter of tubular workpieces was in the range 30…50 mm. The electrode system included wire bridges which were replaced after every discharge. The dies were assembled as clam shell halves. Employment of EHF enabled reduction of the number of manufacturing operations and elimination of welds in the parts which had to be subdivided in several independently formed and later welded subcomponents. The cycle time for proposed EHF process was reported as five minutes.

More recently, a number of studies indicated that very substantial improvement in sheet formability can be achieved due to increased strain rate, reduction of friction, and coining effect of through thickness compression during high speed impact between the die and the blank: Balanethiram and Daehn (1994) for AA6061-T4; Imbert et al. (2005) for AA5754 and 6111-T4; Rohatghi et al. (2014) for AA5182; Dariani et al. (2009) for AA6061-T6 and 1045 steel; Golovashchenko et al. (2013) for DP500, DP590, DP780 and DP980 dual phase steels. Detailed evolution of microstructure and porosity development in quasistatic and electrohydraulic forming clearly explained that high strain rate and high velocity impact create favorable conditions for DP500 and DP780 by Samei et al. (2013).

The intent to find a viable alternative to Explosive Forming processes motivated the development of EMF and EHF processes. Very detailed review on EMF processes discussing coil designs, research results, recently developed numerical and analytical models was published by Psyk et al. (2011). The major limitations of this technology is in quickly diminishing pressure applied to sheet metal blank when it moves away from the coil generating electromagnetic field and in requirement for the material of the blank to have good electrical conductivity. Limited structural strength of the coil which usually includes insulation material as well as the need for high electrical conductivity of the blank limit applications of EMF to aluminum alloys or mild steel. Diminishing pressure as a result of the blank displacement limits application of EMF processes to forming of rather shallow shapes or very smooth shapes where final forming is possible based upon inertial mode of deformation.

From the perspective of forming more complex shapes, EHF processes seem to have the highest potential: as demonstrated by Golovashchenko et al. (2011), sheet metal blank can be formed by sequential discharges of several pairs of electrodes, there is no specific requirement to the grain structure (as for SPF), or electrical conductivity (as in EMF processes). As a result, the pressure distribution applied to the sheet metal blank can be tailored in a rather broad range: multiple discharges from several electrode systems may create more favorable mechanism of filling the die cavity. As demonstrated by Golovashchenko et al. (2011), the blank can be preformed into a shape which better utilizes formability of the entire blank to fill the corners. Homberg et al. (2010) very clearly demonstrated that EHF has much better capability to form sharp corners than quasistatic hydroforming described by Singh (2003) and also requires approximately 30 times less clamping force, which leads to much lower capital investment.

3 Electrohydraulic forming of an automotive panel

EHF technology offers a lot of flexibility of how pressure can be applied and the trajectory of sheet metal flow driven by this pressure. In this study, the problem of forming a part from AHSS DP500 will be discussed. The part represents and interior structural automotive panel. For weight saving target, the mild steel was replaced by DP500 with appropriate gauge reduction. The initial rectangular blank had dimensions of 606mm x 450mm. Forming of the part by traditional drawing technology from DP500 was not feasible. The initial formability analysis was performed based upon numerical simulation with LS Dyna. The results illustrated in Fig.1 clearly show rather substantial strain localization with maximum effective strain of 0.6 in the condition close to plane strain.

Nevertheless, the attempt was made to build an experimental die which still proved that the pulsed forming process might provide insufficient improvement in formability. The reason why this situation occurred maybe explained by rather smooth radii and overall fairly deep cavities which had to be formed by sheet metal stretching in the condition close to plane strain. The formed part is illustrated in Fig. 2.

In order to resolve this issue, the strategy to use a preforming process was employed. The concept of a low cost preforming die was proposed by Golovashchenko (2016). The general idea was to track the areas which are subject to excessively high strains from the final simulation to the initial configuration of the blank. As it can be seen from the simulation results in Fig.1, the adjacent areas experience substantially lower strains. Therefore, a potential solution is to bulge the areas of low stretch and accumulate material which during the forming of the final shape can provide necessary material for filling the cavity instead of stretching the local areas further. This approach lowered the maximum strains in the formed blank from 0.6 to 0.4 by prestraining the adjacent areas with low strain to approximately 0.2.

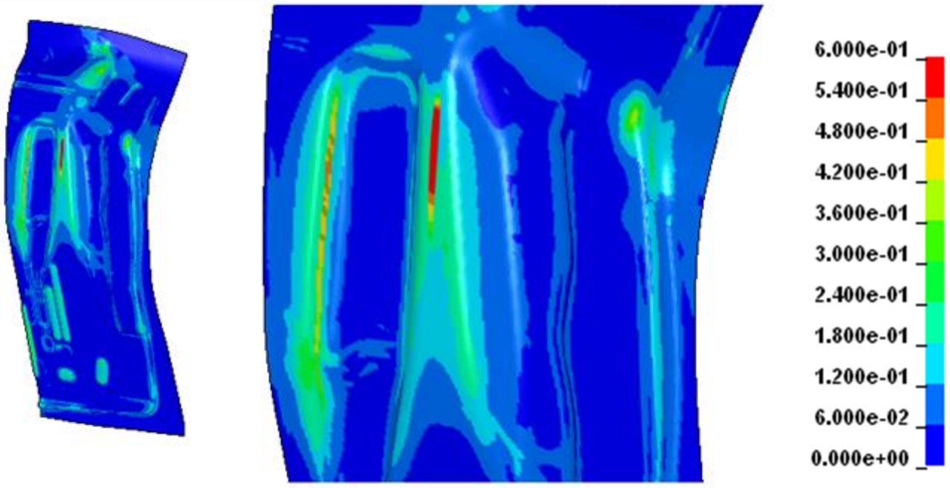

Figure1*: Prediction of effective strain distribution in EHF formed panel (shown up to a symmetry line)*

Figure 2*: Sheet metal part formed with EHF process with multiple parallel cavities requiring substantial sheet metal stretching leading to splitting shown by the arrow.*

EHF forming was performed in a single-pair electrode system. The design of the EHF chamber is described by Mamutov et al. (2015) where it was employed for a rectangular panel forming of similar size. The pulse generator had 200 μF capacitance, 200nH internal inductance and 15kV maximum charging voltage. The experimental component was formed in nine discharges in the following sequence: 8.1kJ; 8.1kJ; 10kJ; 12.1kJ; 14.4kJ; 16.9kJ; 19.6kJ; 21kJ; and 21kJ. The proposed sequence of discharges provided smooth material flow into the die cavity and drawing sheet metal from the flanges. Other discharge sequences were tried, but required either higher energies or larger number of discharges. In general, the motivation was to avoid high speed impact and possible bounce back of the formed sheet. Applying higher energy would likely put the forming die at higher risk as well as likely would not allow the same amount of sheet metal inflow into the die cavity. The last discharge provided final calibration and resulted in very minimum additional material flow into the die cavity.

4 Conclusion

Electrohydraulic forming process enables forming of panels from Dual Phase steels in case the strain level required to fill the shape exceeds formability limit. In discussed process, moderate formability improvement was observed based upon high rate nature of the process. Filling of the die cavity was conducted in nine discharges to allow for smoother materials flow from the flanges. Additional formability benefit was obtained by preforming operation which was based on bulging the areas of low strain adjacent to heavily stretched areas. Filling of all the radii was achieved during final higher energy discharges.

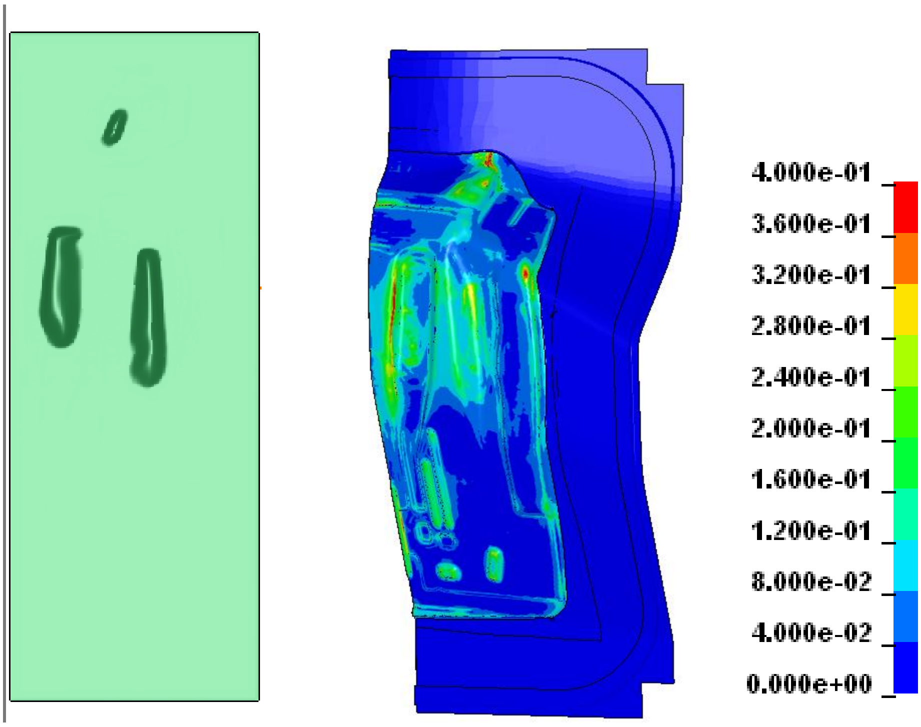

Figure 3: *Results of EHF forming with bulged cavities in a flat sheet (left), lowering the amplitude of effective strain in a formed blank (middle) according to the scale (right).*

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