Electromagnetic Springback Reshaping

E. Iriondo[1], B. Gonzalez[1], M. Gutierrez[1], V. Vonhout[2], G. Daehn[2], B. Hayes[3]

[1] LABEIN Technological Research Center, Automotive Unit. Derio, Spain
[2] Department of Materials Science & Engineering. The Ohio State University. Columbus, OH. USA
[3] Aerojet. Sacramento, CA. USA.

Abstract

Electromagnetic forming is an impulse-based forming technique where high dynamic pressure is distributed to conductive materials by pure electromagnetic interaction. The aim of this paper is to present how springback can be controlled when the EMF technique is used as a second corrective step; bringing formed parts to the desired final shape by means of magnetic impulses in critical areas of the formed components. This analysis is based on the results of two experimental studies. In the first, the selected preformed specimen shape is the L-shape bent part of HSS DP600, in 0.8 and 1.95 mm thickness, and Aluminium Alloy 5754, in 1 and 2 mm thickness. The second geometries are two rocket nozzle panels made of a thick but soft copper alloy. While the geometry and the material are the similar, the first approach of this work was developed using smaller panels (about 30 cm long) and the full size (about 1 m long), in order to study the behaviour of the material and the approximate energy levels required to scale up the full size panels. Overall this study shows EM forming can have a potent effect in controlling springback.

Keywords:

Springback, Residual stress, Electromagnetic forming

1 Introduction

In sheet metal forming, control of elastic recovery of springback is a key in achieving the desired shape. Since all materials have a finite modulus of elasticity, plastic deformation is always accompanied by some elastic recovery when the load is removed. If the stress distribution is non-uniform, distortion will occur in load removal. The amount of springback is defined as the deviation between the final shape at the end of the loading stage and the shape after the part is removed from the forming die. The effect of unloading is equivalent to adding elastic strain distribution to the fully plastic stress state. After unloading, the tension side of the bend has a significant compressive residual stress at the surface and there is residual tensile stress on the inner surface, as shown in Figure 1 [1].

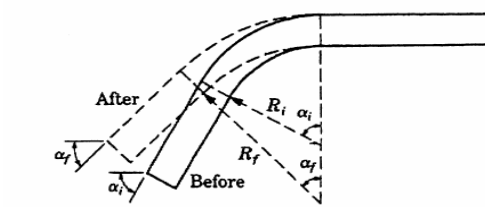

Figure 1: *Schematic of loaded and unloaded stages of a bending process.*

The focus was to analyze the behavior of springback when EM pulse or pulses are applied in an area with residual stresses. The first study selected the optimum energy levels to correct and quantified the deviations from the target geometry. The second study made a comparison between the hot sizing and the EM sizing of the panels.

The basic idea here is that electromagnetic forming can place an impulse in a desired location (set by coil configuration) and of a given energy (set by bank charging). This can be used to put a controlled and reproducible amount (small) of plastic deformation in the part. Either with a single or multiple shots, this can be used to correct for springback.

2 Springback on L-shape bent parts of AA 5754 and DP 600.

The process and materials were chosen based on the use of the AA and HSS in the automotive industry. The most basic operation of its structural components is based on the L-shape section. The objective is to understand the basic behavior of residual stresses under the impulse loading.

2.1 Experiment layout

The experiments have been carried out using electromagnetic impulses as a corrective step after the parts have been shaped by traditional metal forming. The selected specimen shape is the L-shape. The experimental part of the study started with the bending of DP-600 (0.8 and 1.95 mm thickness) and AA-5754 (1 and 2 mm thickness) of 170x100mm blank dimensions. After the bending stage, the springback angle of all L-shape parts was measured.

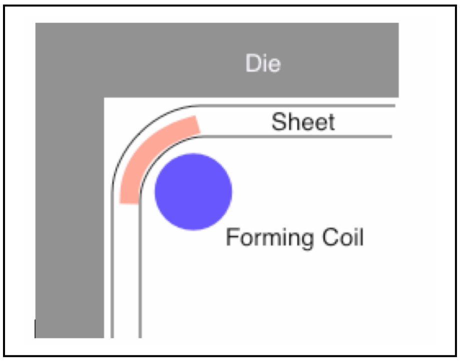

Figure 2: *Schematic diagram of the use of an EM actuator in the corner section.*

The capacitor bank used for discharging the energy through the coil has been the standard 16 kJ Maxwell-Magneform [2] (8.3 kV @ 16kJ), capacitance of 426 μF and inductance of 140 nH. A single turn copper coil, positioned in the bending radius area, has been used for the development of these experiments. The specimen is positioned between the coil and the 90° steel die. After the EM pulse, the 90° die was removed and the final angle of the specimen was measured with an angle gauge. The return path was located below the forming coil to induce a return current in the sheet. This gives reasonable efficiency because there is a full eddy current path.

Input parameter of the process is the energy level discharged by the capacitor bank to each specimen and the output is the final angle between bent part's walls after the EM impulse.

2.2 Springback behaviour. Results

Springback has been corrected in both materials and thickness. The minimum energy discharged, in order to reach 90° between parts walls, was 0.8kJ for the 1mm thickness AA5754 and the maximum, 14.4 kJ, for the 1.95mm DP600.

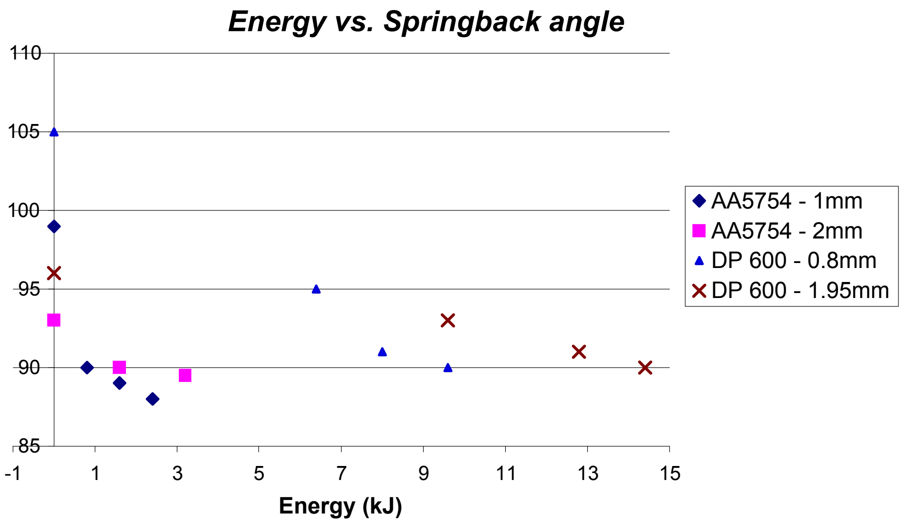

Figure 3: *Springback angles vs. different input energy levels.*

As shown in Fig 3, when we increased the impulse energy to AA5754 specimens of both thickness, from the optimum threshold level quoted before, we found over bending of the specimens as result. The method provides good control on springback angles. Details from the summary in Figure 3 are shown in Figures 4-6.

Some parameters involved are crucial for determining the efficiency of the process and a very important one in the EMF technique, uncommon for the rest of forming processes, is the electrical conductivity of the specimen material. In our case, the conductivity of AA5754 is higher than the DP600. The higher the conductivity of the material, the lower is the inductance resulting in higher EM force and better material forming. Other important factors affecting the final results are usual in sheet metal forming: the strength of the material (4 times higher for the DP-600) and the thickness.

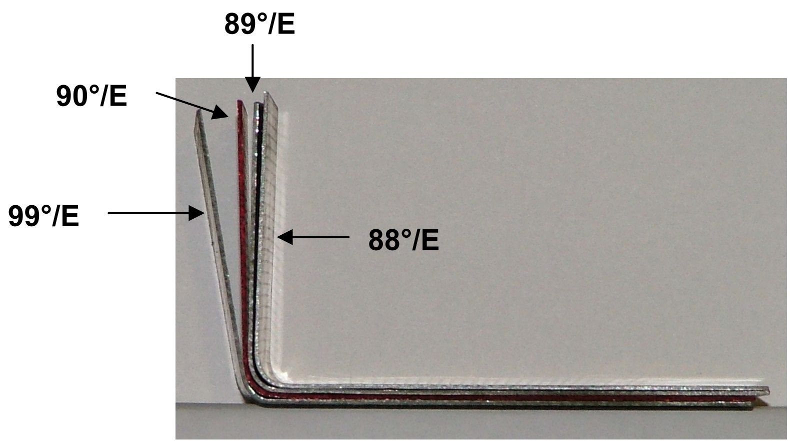

Figure 4: *Springback angle changes, with different energy levels, of AA5754 of 1mm thickness.*

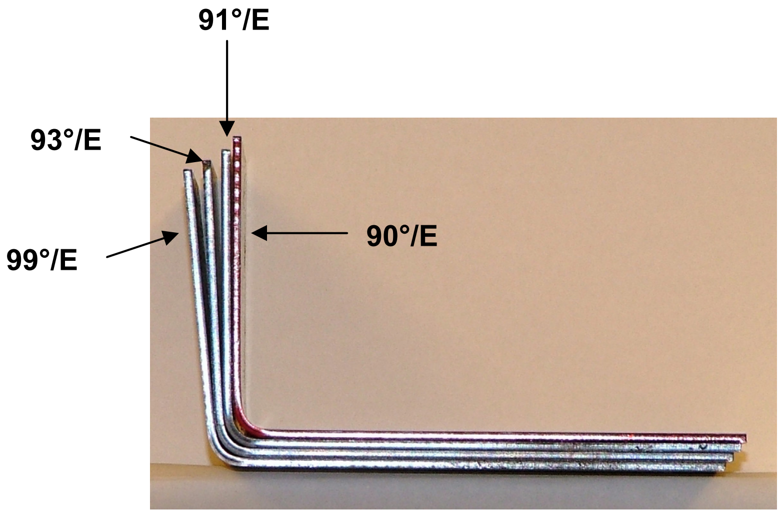

Figure 5: *Springback angle changes, with different energy levels, of DP600 of 1.95mm thickness.*

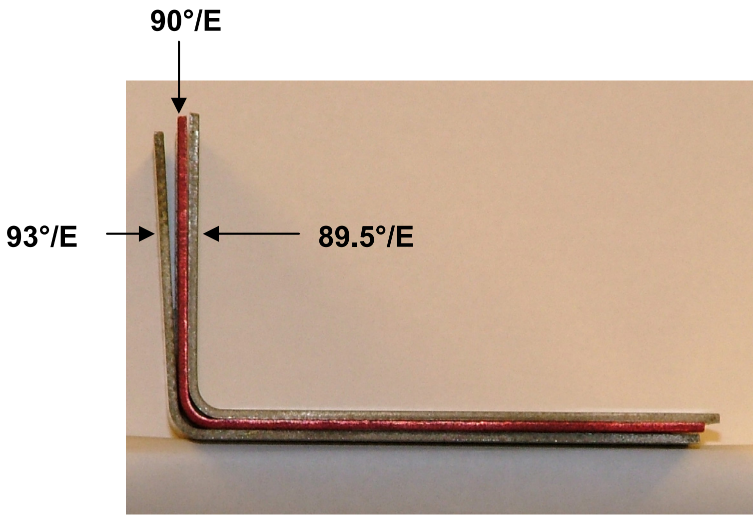

Figure 6: *Springback angle changes, with different energy levels, of AA5754 of 2mm thickness. 90°.*

3 Reshaping of a Rocket Nozzle Panel

This second experimental study follows to a real industrial problem of dimensional accuracy. Aerojet has developed process for stamping and assembling soft copper alloy rocket nozzle segments and springback leads to unacceptable final dimensions without hot sizing, which causes internal microcracking. The final aim of this study is to compare the geometrical accuracy obtained by the hot sizing and the electromagnetic pulses.

EM reshaping was carried out with first a sub-sized panel and second a full-size panel. The same capacitor bank and protocol were used for both the subsize and full size panels.

3.1 Experimental Layout

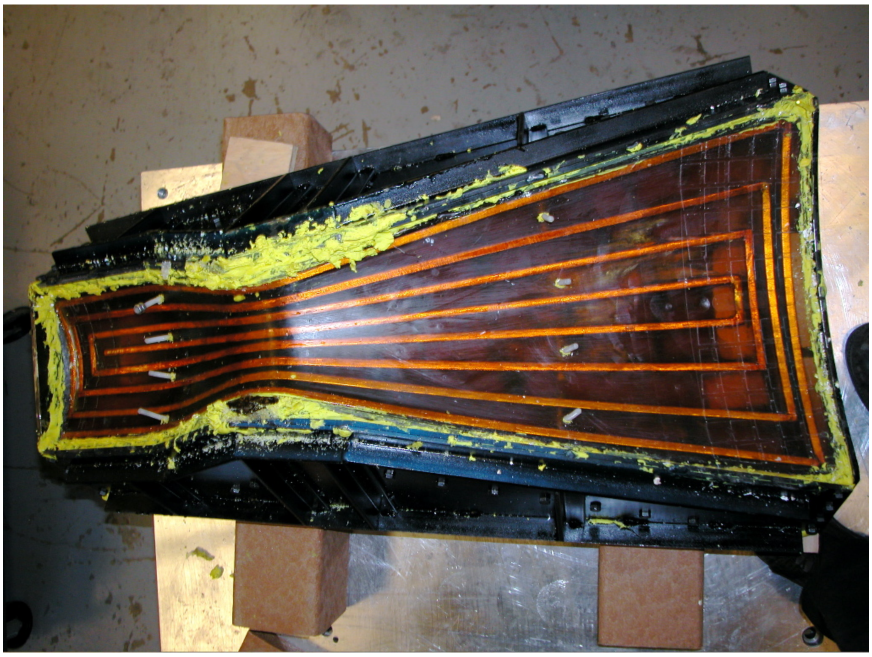

Figure 7: *Photograph of the coil used to reshape the full-sized liner.*

The capacitor bank used for discharging the energy through the coil has been the 48 kJ Maxwell-Magneform [2] (10 kV @ 48kJ. A multi turn copper coil has been used for the development of these experiments. The specimen, with blue impression on the die surface to impact, is positioned between the coil and the target geometry die, which are simulating the work press on the close stage. After the EM pulse, the panel was removed from the tooling, and the specimen was positioned on a mold with target dimension. The impression blue marks on the panel, which indicate the pressure distribution, and the dimensional error assessed by feeler gauge, are the output.

3.2 Small nozzle

The corrective impulses applied, by a multi turn coil to this component of about 300mm long, 6mm thickness and 1.6 kg in weight, had a different character at this experimental development. If in the previous works the objective was to find the minimum energy level for correcting the deviation in one shot, in this case multiple shots of the same energy were carry out.

Figure 8: *Small rocket nozzle panel.*

Input parameters of this work are the energy level discharged by the capacitor bank and the standoff distance between the panel and the die to impact. The output is the dimensional deviation from the target geometry.

The best result was obtained by 10 repetitions of 4.8kJ and the standoff factor isn't going to be an input on the full size experiments because equivalent shape registry has been available with and without it.

3.3 Full size nozzle reshaping

During this phase of the study, a multi turn coil was applying EM pulses to the full size rocket nozzles of 1m length, 10mm thickness and 19 kg in weight. Equal to the previous phase, at this case multiple shots of the same energy were carry out

Energy levels required for improving the results of the hot sizing are below 15 kJ applied in multiple forming discharges between 3 and 10.

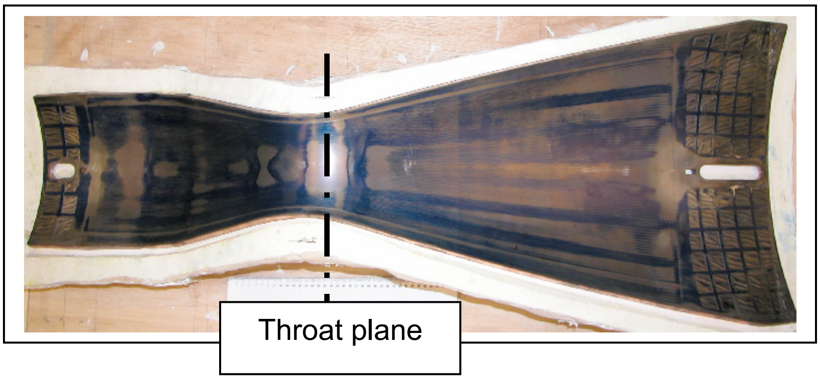

Figure 9: *Full size rocket nozzle panel. Showing impression blue imprint after forming*

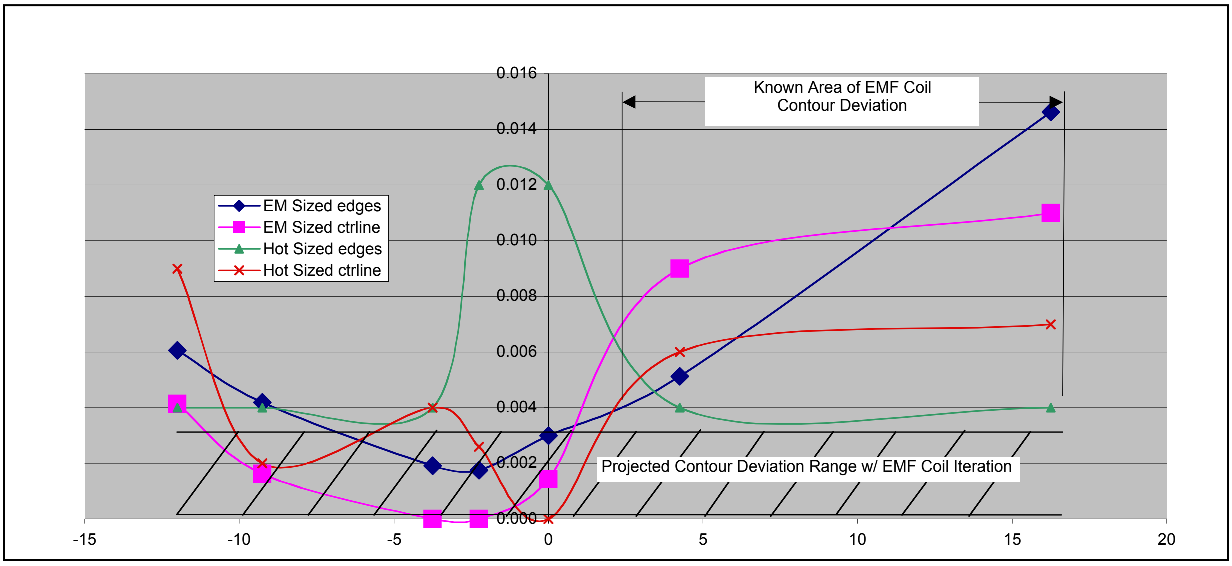

Figure 10: *Comparision of EM and hot sizing results.*

The comparison plotted in Fig 9 as a dimensional summary of this study, shows the geometrical improvement reached using EM pulses: eliminating the undesired effect of microcracking and obtaining a more uniform surface.

4 Conclusions

The analysis of our experimental results confirms that Electromagnetic forming is an effective technique for eliminating the springback.

- The most important "new" parameter to take into account on this process is the conductivity of the material
- This innovative technique opens an alternative to the springback correction
- The tooling for this method is relatively simple and very flexible even to couple it into an industrial configuration.

References

[1] *Hu, J.; Marciniak, Z.; Duncan, J.*: Mechanics of Sheet Metal Forming, Butterworth Heinemann. 2002

[2] www.magneform.com