Journal of Manufacturing Processes 15 (2013) 183–193

Contents lists available at SciVerse ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Technical paper

Shape calibration of high strength metal sheets by electromagnetic forming

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ARTICLE INFO

Article history:
Received 1 September 2012
Received in revised form 8 January 2013
Accepted 26 January 2013
Available online 7 March 2013

Keywords:
Electromagnetic forming
Springback calibration
High strength steels

ABSTRACT

Electromagnetic (EM) forming is an emerging technique that is gaining acceptance for its complementary benefits to conventional metal forming techniques. In this work an innovative application of this impulse forming technique has been demonstrated: the EM shape calibration and correction of springback (sidewall curl) of DP600 and TRIP700 high strength steel (HSS) workpieces. This method has been applied as a second corrective step to previously deep drawn U-channels. The experimental results confirm the sidewall curl angle correction, achieving them with a 22 kJ discharge for DP600 samples and 24 kJ for TRIP700.

On the other hand, an uncoupled multiphysical simulation strategy has been carried out in order to virtually validate the EM shape calibration method. The EM fields were simulated by Maxwell 3D and then the Pamstamp code was used to obtain the deformation process.

1. Introduction

In recent years, concepts and ideas such as sustainable development, lightweight structures/components, reductions in fuel consumption and emissions have been of key importance in vehicle design and manufacturing. This drives the automotive research community to deal with new materials and processes in order to reduce the vehicle weight, while maintaining safety requirements and increasing the comfort level. In this regard, high strength steels (HSS) have a great applicability in thin-wall structures for their optimal weight/strength ratio.

Nevertheless, HSS accentuate already existing problems, such as "springback". This term is related to the shape discrepancy between the fully loaded and unloaded configurations. On unloading elastic strains are recovered and residual stresses are redistributed throughout the sheet thickness, thus producing geometrical deviation from the target [1,2]. During the last years, an important effort has been made in order to predict and correct this phenomenon by FEM tools [3–5].

This research work attempts to give a new approach to solving this outstanding problem. A workable solution is found in the EM Calibration: an EM force provides mechanical impulse to the deep drawn parts as a reshaping step.

The aim is to develop a method for calibrating the HSS U-shape profiles obtained in a deep drawing operation by means of EM impulses. In a previous work, Iriondo et al. have been able to resize a L-shape profiles in Aluminum Alloy A-5754 and Dual Phase 600 steel [6]. Based on the bent part correction, a predictive model was carried out to estimate the minimum energy requirement for EM calibration [7].

Besides the experimental results, the method will also be validated using an uncoupled simulation strategy. The two software packages used are Maxwell 3D for the EM simulation and Pamstamp 2G in applying the mechanical forming step.

2. A new calibration method – experimental approach

In a work by Golovashchenko et al. [8], it is presented a method for springback reduction by clamping a conventionally formed workpiece to a die, with the target geometry, and applying a pressure pulse to the workpiece to relieve the internal stresses. According to this work, springback is reduced or eliminated because the applied electromagnetic force on a fixed part results in elastic waves running back and forth through the thickness of the part multiple times, thus relieving its internal residual stresses. It is showed that 90% or more of the internal stresses causing springback were eliminated by the EMF treatment.

The exact mechanism by which springback is reduced is not fully clear at this point. The elastic strains due to forming must be relieved or corrected. The repulsive force generated between the field of the coil and the current induced in the nearby material,

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http://dx.doi.org/10.1016/j.jmapro.2013.01.007

Table 1
Physical properties of DP600 and TRIP700.

Material	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)	Elastic modulus (GPa)	Electrical resistivity (n Ωm)
DP600	360	600	25	210	170
TRIP700	420	700	30	210	170

certainly is able to produce plastic deformation in the metal. The deformation can be enhanced by the magnetoplastic effect, which is thought to cause a deepening of the dislocations.

This section presents the experimental arrangement used to modify the sprung shape. The target of the experimental work is to obtain 90° angles in both bent radii while maintaining the flanges and base parallel to one another. The sidewalls are expected to be flat, without any curled appearance.

2.1. Preliminary deep drawing results

A conventional deep drawing forming process has been carried out to produce the required set of samples to proceed with the calibration method, in a second corrective step. The resulting U-channels have intensively curled sidewalls [9,10].

The experiments were carried out with 300 mm × 100 mm × 1 mm thickness samples of DP600 and TRIP700, the longest dimension being along the rolling direction of the material. Table 1 shows the physical properties of DP600 and TRIP700.

The process starts with the introduction of the blank into the tooling. When the blank is positioned, in contact with the central block (or punch), the blankholders (with double pressure pad) clamp the blank. Once the blankholder is fully loaded, the process goes on by the tooling advancing down and drawing the walls of the U-channel. A 800 Tn hydraulic press was used and a 40 Tn blank holder force was applied to clamp all the non-lubricated blanks.

The equipment used to form the blanks is the U-channel deep drawing tooling. Fig. 1(a) shows this tooling assembled at the press.

One of the deep drawing parameters affecting the resulting springback and sidewall curl is the entry radius of the tooling, constrained by design [11]. In this case, the punch bottom and die entry radii are both 5 mm.

Geometrical deviations to be controlled are centered on the difference between the target (last forming step) and the unloading geometry, affected by springback (Fig. 2). Two new parameters are introduced for this purpose:

- *D*1 (*Y* axis): total height of the U-channel.
- *D*2 (*X* axis): deviation or opening distance in the *X* direction.

*D*1 target value is 81 mm while the corresponding value for *D*2 is 0. After forming, the average experimental *D*1 value for DP600 is 71.6 mm while that for TRIP700 is 69.4 mm. *D*1 values of TRIP700 are slightly lower than those of DP600 in consequence of its higher strength. On the other hand, *D*2 value for DP600 is 22.1 mm and that for TRIP700 is 24.8 mm.

2.2. Electromagnetic forming technology

Basically an electromagnetic forming system consists of a capacitor bank, a conductive actuator and the metallic workpiece to be deformed. The capacitor bank is connected to an actuator or coil, which is near the sheet workpiece. When the main switch is closed, a large current flows through the coil and produces a transient magnetic field that induces eddy currents in the nearby metallic sheet [12]. According to Lenz's law, the currents travel in opposite directions in the actuator and the metallic workpiece. The EM repulsion between the opposite charged currents, governed by Lorentz force expression, provides acceleration and deformation of the workpiece. Detailed reviews of the fundamentals of this technology have been published by Belyy et al. [13] and Psyk et al. [14].

2.3. Experimental procedure

Some guidelines and limitations are to be taken into account in the coil design procedure.

With the aim of calibrating each sidewall separately, two shots are required. The whole sidewall is the area where the EM impulse will be applied [15]. The embedded coil system follows the criteria of avoiding the Rebound Effect [6]. The EM coil is integrated into the tooling in order to simulate the last forming step before the unloading process.

A 1 mm gap is introduced between the blank and the die profile. This is the optimal distance to take advantage of the inertial ironing effect when the sheet part contacts the die. With the coil being embedded in the punch, the convex surfaces of the sidewall are in contact with the coil. The combination of the contact between the coil and the sidewall and the 1 mm gap in the rest of the sidewall area, increases the shot efficiency, hence yielding a higher pressure.

Based on the high energy requirements, HSS with low electrical conductivity are to be formed. A low inductance coil is employed to provide a high rising frequency, small skin depth and better efficiency [16].

According to the above observations, the designed EM coil is shown in Fig. 3a, where the arrows correspond to the currents during the discharge and the blue square represents the sidewall to be calibrated. The winding is manufactured from Copper 110.

The EM coil has a section of 8.5 mm × 8.5 mm and is 160 mm long. In order to insulate the current from the steel tooling and the

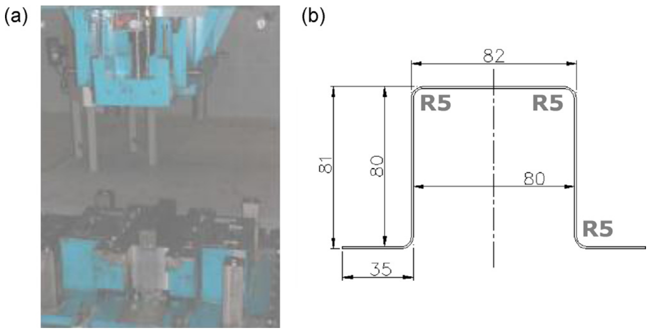

Fig. 1. (a) Photograph of the tooling used to deep draw the U-channel. (b) The target geometry of the final U-channel [7].

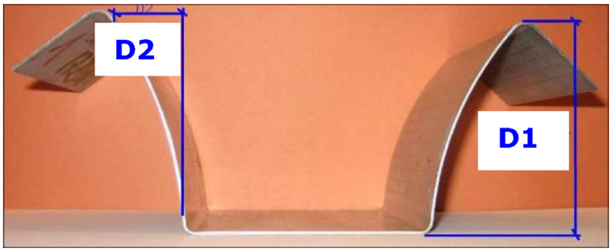

Fig. 2. Photograph of *D*1 and *D*2 of a deep drawn TRIP700 U-channel [7].