Jurnal
Teknologi

Full Paper

AHSS AUTO STAMPING CHALLENGES: RECTIFYING SPRINGBACK

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Article history
Received
02 June 2015
Received in revised form
09 August 2015
Accepted
1 September 2015

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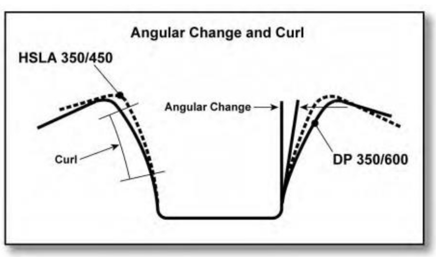
Graphical abstract



Abstract

To improve crash worthiness and fuel economy, the automotive industry is, increasingly, using Advanced High Strength Steel (AHSS). The main reason to utilize AHSS is their better performance in crash energy management, which allows one to down gauge with AHSS. In addition, these engineered AHSS address the automotive industry's need for steels with higher strength and enhanced formability. The improved capabilities the AHSS bring to the automotive industry do not bring new forming problems but certainly accentuate problems already existing with the application of any higher strength steel. These concerns include higher loads on presses and tools, greater energy requirements, and increased need for springback compensation and control. Springback problem, consistently, is one of the leading roadblocks hindering auto stamping productivity. This paper describes the origins and types of springback, characterizes what causes it, and elaborates ways to rectify it through, stabilization, compensation, and verification.

Keywords: Advanced high strength steel, automotive industry, formability, springback

1.0 INTRODUCTION

Progressive stamping is a metalworking method that can encompass: Blanking; Punching; Coining; Bending; Perforating; Piercing; Notching; Drawing; Lancing; Embossing; and several other ways of modifying metal raw material, combined with an automatic feeding system. The feeding system pushes a strip of metal (as it unrolls from a coil) through all of the stations of a progressive stamping die. Each station performs one or more operations until a finished part is made. The final station is a cut off operation, which separates the finished part from the carrying web [1].

To improve crash worthiness and fuel economy, the automotive industry is, increasingly, using Advanced High Strength Steel (AHSS). Today, and in the future, automotive manufacturers must reduce the overall weight of their cars. The most cost-efficient way to do this is with AHSS. However, there are several parameters that decide which of the AHSS types to be used; the most important parameters are derived from the geometrical form of the component and the selection of forming and blanking method. The main reason to utilize AHSS is their better performance in crash energy management, which allows one to down gauge with AHSS. In addition, these engineered AHSS address the automotive industry's need for steels with higher strength and enhanced formability. The improved capabilities AHSS bring to the automotive industry do not bring new forming problems but certainly accentuate problems already existing with the application of any higher strength steel. These concerns include higher loads on presses and tools, greater energy requirements, and increased need for springback compensation and control. In addition, AHSS have greater tendency to wrinkle due to lack of adequate hold-down and often a reduction in sheet thickness. Springback problem, consistently, is one of the leading roadblocks hindering auto stamping productivity. However, knowing what causes it and to rectify it through; stabilization, compensation, and verification, can help to overcome the problem [2].

2.0 SPRINGBACK

Dimensional control is extremely important when stamping automotive parts. Newer steels all exhibit specific stress-strain curves, resulting in unique springback levels and behaviours. Springback, the tendency for a material to return to its pre-formed position has negative consequences for part dimensions. In order for parts to be manufactured in large volumes, each part must be reproducible hit after hit. Auto part stampers must look at how to compensate for springback by examining all the variables in the manufacturing process including tooling, part shape and the machinery itself to ensure volume production repeatability [3].

Today the primary emphasis has shifted to accuracy and consistency of product dimensions. These dimensional problems are a function of the elastic stresses created during the forming of the part and the relief of these stresses, or lack thereof, during the unloading of part after each forming operation. These dimensional problems or springback are created in all parts. However, their magnitude generally increases as the strength of the steel increases; springback of AHSS is different from springback of HSLA (High Strength Low Alloy) steels as shown in Figure 1. The two channels were made sequentially in a draw die with a pad on the post. The strain distributions between the two parts were very close with almost identical lengths of line. However, the stress distributions were very different because of the steel property differences between DP (Dual Phase) and HSLA steels, hence the difference in the severity of springback [4].

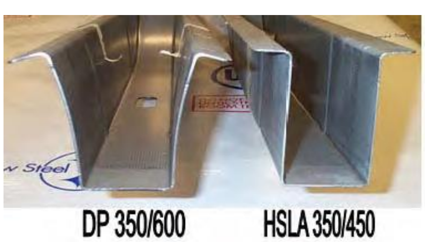


Figure 1 Two channels made sequentially in the same die

When sheet metal is plastically deformed into a part, the shape of the part always deviates somewhat from the shape of punch and die after removal from the tooling. This dimensional deviation of the part is known as springback. Springback is caused by elastic recovery of the part, which can be illustrated simply on the stress-strain curves shown in Figure 2.

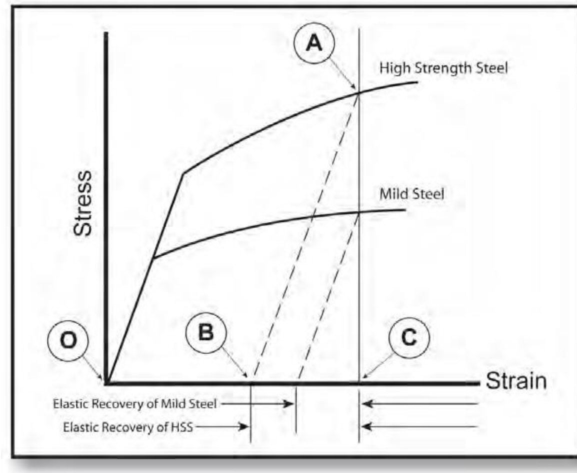


Figure 2 Schematic showing amount of springback is proportional to stress

The magnitude of springback is governed by the tooling and component geometry. When part geometry prevents complete unloading (relaxing) of the elastic stresses, the elastic stresses remaining in the part are called residual stresses. The part then will assume whatever shape it can to minimize the total remaining residual stresses. If all elastic stresses cannot be relieved, then creating a uniformly distributed residual stress pattern across the sheet and through the thickness will help eliminate the source of mechanical multiplier effects and thus lead to reduced springback problems. In general, springback experienced in AHSS parts is greater than that experienced in mild or HSLA steels.

3.0 TYPES OF SPRINGBACK

Three modes of springback commonly found in channels and under body components are: Angular Change; Sidewall Curl; and Twist.

3.1 Angular Change

Angular change sometimes called springback, is the angle created when the bending edge line (the part) deviates from the line of the tool. The springback angle is measured off the punch radius (Figure 3). If there is no sidewall curl, the angle is constant up the wall of the channel.

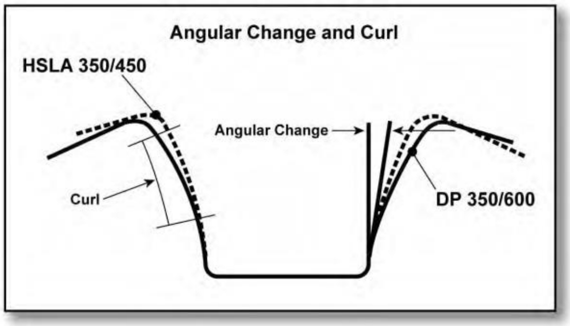


Figure 3 Schematic showing difference between angular change and sidewall curl.

Angular/cross-section change is caused by stress difference in the sheet thickness direction when a sheet metal bends over a die radius. This stress difference in the sheet thickness direction creates a bending moment at the bending radius after dies are released, which results in the angular change. The key to eliminating or minimizing the angular change is to eliminate or to minimize this bending moment.

3.2 Sidewall Curl

Side wall is the curvature created in the side wall of a channel (Figures 1 & 3). This curvature occurs when a sheet of metal is drawn over a die/punch radius or through a draw bead. The primary cause is uneven stress distribution or stress gradient through the thickness of the sheet metal. This stress is generated during the bending and unbending process.

During the bending and unbending sequence, the deformation histories for both sides of the sheet are unlikely to be identical. This usually manifests itself by flaring the flanges, which is an important area for joining to other parts. The resulting sidewall curl can cause assembly difficulties for rail or channel sections that require tight tolerance of mating faces during assembly. In the worst case, a gap resulting from the sidewall curl can be so large that welding is not possible.

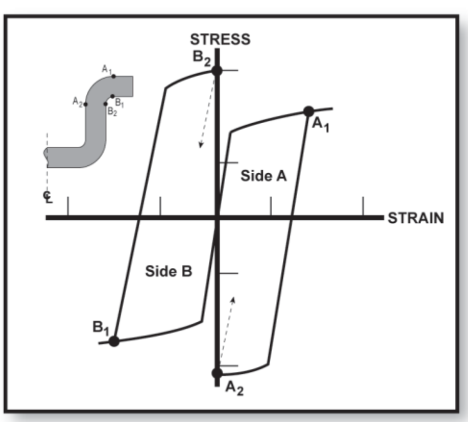


Figure 4 Origin and mechanism of sidewall curl

Figure 4 illustrates in detail what happens when sheet metal is drawn over the die radius (a bending and unbending process). The deformation in side A changes from tension (A1) during bending to compression (A2) during unbending; in contrast, the deformation in side B changes from compression (B1) to tension (B2) during bending and unbending. As the sheet enters the sidewall, side A is in compression and side B is in tension, although both sides may have similar amounts of strain. Once the punch is removed from the die cavity (unloading), side A tends to elongate and side B to contract due to the elastic recovery causing a curl in the sidewall.

This difference in elastic recovery in side A and side B is the main source of variation in sidewall curl along the wall. The higher the strength of the deformed metal, the greater the magnitude and difference in elastic recovery between sides A and B and the increase in sidewall curl. The strength of the deformed metal depends not only on the as-received yield strength, but also on the work hardening capacity. This is one of the key differences between conventional HSS and AHSS. Clearly, the rule for minimizing the sidewall curl is to minimize the stress gradient through the sheet thickness [4].

3.3 Twist

Twist is defined as two cross-sections rotating differently along their axis. Twist is caused by torsion moments in the cross-section of the part. The torsional displacement (twist) develops because of unbalanced springback and residual stresses acting in the part to create a force couple, which tends to rotate one end of the part relative to another. As shown in Figure 5 the torsional moment can come from the in-plane residual stresses in the flange, the sidewall, or both.

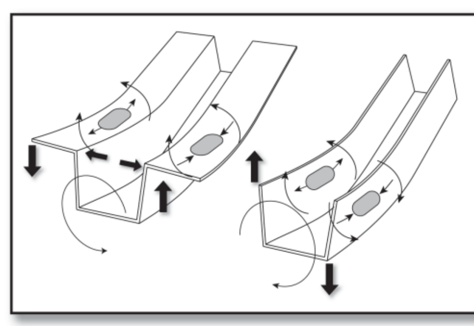


Figure 5 Torsion Moment created flange or sidewall residual stresses

The actual magnitude of twist in a part will be determined by the relationship between unbalanced stresses on the part and the stiffness of the part in the direction of the twist. Low torsional stiffness values in long, thin parts are the reason high aspect ratio parts have significantly higher tendencies to twist. There is also a lever effect, whereby the same amount of twist will result in a larger displacement in a long part than would be the case in a shorter part with a similar twist angle. The tendency for parts to twist can be overcome by reducing the imbalance in the residual stresses forming the force couple that creates the torsional movement. Unbalanced forces are more likely in unsymmetrical parts; parts with wide flanges or high sidewalls and in parts with sudden changes in cross section. Parts with unequal flange lengths or non-symmetric cut outs will be susceptible to twist due to unbalanced springback forces generated by these non-symmetrical features [4].

4.0 RECTIFYING SPRINGBACK

Forming of a part creates elastic stresses unless the forming is performed at a higher temperature range where stress relief is accomplished before the part leaves the die. An example of the latter condition is HF (Hot Formed) steels. Therefore, some form of springback correction is required for bringing the part back to part print. This springback correction can take many forms.
The first approach is to apply an additional process that changes undesirable elastic stresses to less damaging elastic stresses. One example is a post-stretch operation that reduces sidewall curl by changing the tensile to -compressive elastic stress gradient through the thickness of the sidewall to all tensile elastic stresses throughout the thickness. Another example is over-forming panels and channels so that the release of elastic stresses brings the part dimensions back to part print instead of becoming undersized.
A second approach is to modify the process and/or tooling to reduce the level of elastic stresses actually imparted to the part during the forming operation. An example would be to reduce sidewall curl by replacing sheet metal flowing through draw beads and over a die radius with a simple 90 degree bending.
A third approach for correcting springback problems is to modify product design to resist the release of the elastic stresses. Mechanical stiffeners are added to the part design to lock in the elastic stresses to maintain desired part shape.

4.1 Change the Elastic Stresses First Approach

Post-Stretch: one of the leading techniques for significant reduction of both angular change and sidewall curl is a Post-Stretch operation. An in-plane tension is applied after the bending operations in draw beads and die radii to change tensile to compressive elastic stress gradients to all tensile elastic stresses.
When the part is still in the die, the outer surface of the bend over the punch radius is in tension (Point A in Figure 6), while the inner surface is in compression (B). Upon release from the deforming force, the tensile elastic stresses (A) tend to shrink the outer layers and the compressive elastic forces (B) tend to elongate the inner layers. These opposite forces form a mechanical advantage to magnify the angular change. The differential stress can be considered the driver for the dimensional change. In the case of side wall curl this differential stress increases as the sheet metal is work-hardened going through draw beads and around the die radius into the wall of the part.

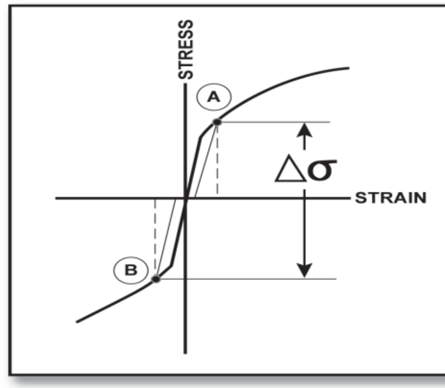


Figure 6 Sheet metal bent over a punch radius has elastic stresses of the opposite sign creating a mechanical advantage to magnify angular change (Similar effects create sidewall curl for sheet metal pulled through draw beads and over die radii)

To correct this angular change and sidewall curl, a tensile stress is applied to the flange end of the wall until an approximate minimum tensile strain of 2% is generated within the sidewall of the stamping. The sequence is shown in Figure 7. The initial elastic states are tensile (A1) and compressive (B1). When approximately 2% tensile strain is added to A1, the strain point work hardens and moves up slightly to A2. However, when 2% tensile strain is added to B1, the compressive elastic stress state first decreases to zero, then climbs to a positive level and work hardens slightly to point B2. The neutral axis is moved out of the sheet metal. The differential stress now approaches zero. Instead of bending or curving outward, the wall simply shortens by a small amount similar to releasing the load on a tensile test sample. This shortening of the wall length can be easily corrected by an increased punch stroke.

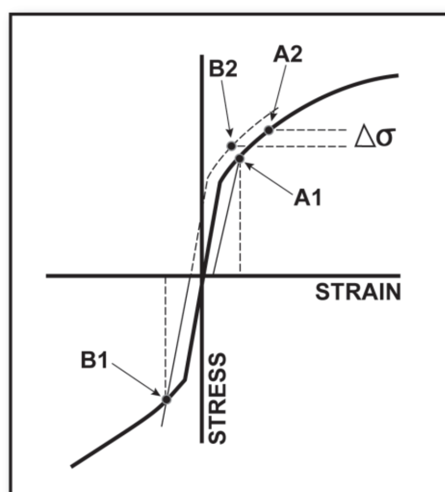


Figure 7 When subjected to a 2% tensile strain, the stress differential (shown in Figure 4) is now reduced to a very small amount

4.2 Over-Forming

Many angular change problems occur when the tooling either is constructed to part print or has insufficient springback compensation; over-forming or over-bending is required. Rotary bending tooling should be used where possible instead of flange wipe dies. The bending angle can be easily adjusted to correct for changes in springback due to variations in steel properties, die set, lubrication, and other process parameters. In addition, the tensile loading generated by the wiping shoe is absent. Multiple stage forming processes may be desirable or even required depending on the part shape. It is recommended to utilize secondary operations to return a sprung shape back to part datum. Care must be taken though to ensure that any subsequent operation does not exceed the work hardening limit of the worked material. It is recommended to use multi-stage computerized forming-process development to confirm strain and work hardening levels and fold the sheet metal over a radius instead drawing or stretching. Cross-section design for longitudinal rails, pillars, and cross members can permit greater springback compensation.

If over-bend must be incorporated for some parts to minimize angular change it is recommended to use tool/die radii less than the part radius and use back relief for the die/punch (Figure 8). If necessary, one or two extra forming steps should be added; such as using pre-crown in the bottom of channel type parts in the first step and flattening the crown in the second step to eliminate the springback at sidewall.

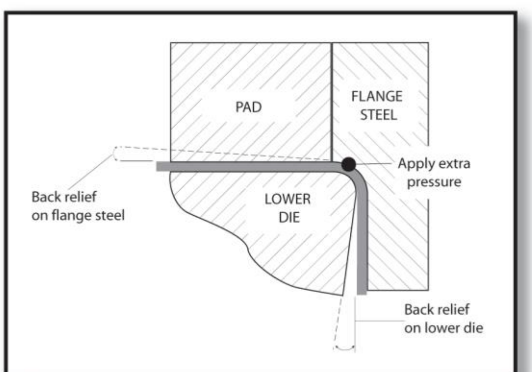


Figure 8 Over-bending is assisted when back relief is provided on the flange steel and lower die

5.0 DISCUSSION

A good quality part is a part without any defects (no fracture or wrinkle), with good surface finish and with desired dimensions. Manufacturing a good quality part is the ultimate goal of the auto metal forming industry. If the problem is inaccurate dimensions due to the elastic recovery of the part after the load is removed, springback needs to be investigated. Springback can be predicted by utilizing finite element analysis (FEM) and the part can be formed to desired dimensions. The accuracy of springback predictions with FEM depends on the material properties such flow stress and E-modulus. The deformation is usually biaxial in stamping. Thus, flow stress should be obtained under biaxial conditions (either by bulge or dome tests). In addition, E-modulus is assumed to be constant during deformation. However, E-modulus decreases with strain in AHSS; the accuracy of the springback predictions can be improved by considering variable E-modulus in FEM. By performing different bending tests such air bending, U-bending, U-flanging and S-shape forming tests the effect of variable E-modulus on springback predictions changes with the magnitude and the type of deformation can be determined (Sever, 2012). The magnitude of springback correlates with elastic modulus and the hardening behaviour of sheet material; there are a number of literatures on modelling of springback in forming AHSS.

In a microscopic view, elastic modulus can be dependent on alloying elements, the grain size and pile-up of dislocations near to grain boundary [5][6]. The slope of the elastic modulus variation is different during loading and unloading, and the difference is due to micro-plastic strain, which does not overcome the barriers set up during forward flow nor created storage of a new dislocation network [7]. In an experiential study [8] it was found that the change in elastic modulus decreased from 6 to 12 % for mild steels and from 9 to 25% for AHSS when the strain increased from 1 to 5%. While, in another study it was found that elastic modulus was not changed with pre-strain during loading process [9]. Consequently the investigation of elastic modulus variation during loading and unloading, and the development of an evolution model that can explain this behaviour adequately would improve the accuracy of springback prediction in FEM.

In sheet metal forming, the thorough understanding of the hardening models which describe the proper material behaviour is very important for accurate springback prediction [10]. The mathematical theory of "elastoplasticity" is now well understood. Isotropic hardening model may not be so effective when the material undergoes non-monotonous deformations [11]. General guidelines for form dies and part design have been developed to minimize and compensate springback in forming AHSS [4]. Using the flexibility of speed and position control in servo-motor driven press, the effect of forming speed, dwelling time at bottom dead centre and the sheet thickness on springback was investigated with ultra-high-strength steel and no effect of forming speed and dwell time on springback was found [12]. Springback of automotive stamping designs were studied with various AHSS and the maximum springback was observed in the highest strength material, DP980 [13]. These studies of springback with actual parts conclude that a better model representing the unique forming characteristics of AHSS such as the change of unloading elastic modulus with increasing plastic strain, Bauschinger effect and kinematic hardening needs to be adequately modelled in FE simulations for accurate springback predictions. Therefore, a fundamental understanding of springback, including the determination of the effects of elastic modulus and hardening behaviour, is necessary to improve the status of forming technology for AHSS [14].

Volume Morphing has also been used to compensate stamping springback. The method is based on the technique of volume morphing. Volume morphing reshapes regions of surfaces or meshes by reshaping volumes containing those regions. The method is applied in an automotive setting and used to compensate springback in sheet metal stampings. Springback data consists of displacement vectors distributed throughout a panel. These vectors can be node displacements predicted by finite element analysis or calculated by the measurements from a scanned die try-out panel. The displacements are much smaller than the lengths and widths of panels and generally affect large regions of the panel. There are many options to create the various types of volumes and boundary conditions for specific applications. Features include global morphing, local region morphing, iterative morphing as well as methods to interpolate or modify the displacement vectors [15].

6.0 CONCLUSION

Springback is elastic deformation; it is inherent to all stamped sheet metals. Dies are an attempt to impart permanent, or plastic, deformation into the sheet metal product. AHSS exhibit both elastic and plastic deformation tendencies. Elastic deformation is the non-permanent deformation that allows a spring to return to its original size, plastic deformation is the permanent shape change intended for the part. Angular change and sidewall curl escalate with increasing as-formed yield strength and decrease with increasing material thickness. For equal yield strengths, DP steels exhibit more angular change and sidewall curl than conventional HSLA steels. The springback behaviours of TRIP steels are between DP and HSLA steels. The sidewall curl appears to be more sensitive to the material and set-up in a channel draw test. The angular change decreases with smaller tooling radii and tool gap, but sidewall curl show mixed results for smaller tooling radii and tool gap. Both angular change and sidewall curl are reduced with a larger draw bead restraining force. Numerous process modifications are available to remove (or at least minimize and stabilize) the different modes of springback found in channels and similar configurations.

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