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Design of Springback-Free Structural Stamped Part

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ABSTRACT

There is always contradicting requirements between the product designer and the tool designer. This is particularly true in the case of sheet metal stamping process. The former is concerned with aesthetic appearance of the final geometry while the latter prefers simplicity in the tool design. Sheet metal stamped part design is limited by its material ability to deform according to the desired geometry without defect or failure. One of such defect is called springback, which is an inherent property of a sheet metal's tendency to return to its original shape after stamping. This springback error will cause the final part geometry to deviate from its original intended shape. It is a sole responsibility of the tool designer to ensure this will not happen. Current practice of overcoming this problem is by the die face compensation technique whereby modification of the die surface is made in such a way that the sheet metal will be slightly over deformed. In this paper, a new methodology for eliminating this problem is proposed. Springback compensation is now incorporated at the early stage of part design. This is achieved by adding a series of beads generated by topography optimization onto the original part geometry. Springback analysis is finally carried out on the modified geometry by using commercial Computer Aided Engineering (CAE) software to validate the concept.
KEYWORDS: Springback Compensation, Sheet Metal Forming, Topography Optimization, High Strength Steel.

INTRODUCTION

Springback is an inherent property of a sheet metal's tendency to return to its original shape after stamping. It causes the final part geometry to deviate from its intended design shape. Therefore, this factor must be taken into consideration when designing a stamped part. For automotive stamped parts, a tolerance of ±0.5mm [1] is generally de facto standard. Springback severity depends on many factors such as yield stress, Young's modulus and other material properties. Thus, high strength steel (HSS) whose yield stress is above 400MPa is more prone to springback when compared to general forming steels. On the contrary, material like aluminium is also prone to springback due to its low Young's modulus. In general, springback can be controlled in three ways: traditional techniques, process control and die face compensation. The traditional techniques include activities such as over-bending or re-striking. This may not be suitable for high strength steels. On the shop floor, the springback errors can also be minimized by modifying the process control. These can be done by adding stiffener beads, draw beads, optimizing die gaps or even modifying die addendum. In [2] suggested the introduction of partial bead on die and width reduction of part geometry. The last method of overcoming springback is by die compensation i.e. modifying the die face which will be discussed in detail below. The ability to accurately and reliably predict the phenomenon of springback at the early stage of tool development is of prime importance to tool maker in order to avoid the costly die repair prior to production. To this end, springback predictive models have been proposed both analytical and numerical by many authors. Both methods required experimental data for validation.

The analytical approach requires very complex equations in describing the springback phenomena. For instance, in [3] used several steps involving the definition of stress strain for the deformed part, computation of bending moment, the analysis of geometry associated with the tool set up and finally calculation of springback. In the statistical approach, in [1] methods such as Design of Experiment (DOE) and multi-regression are used to derive a predictive model based on historical data. However, the model is limited to particular shape geometry only. The most widely used method for predicting springback is by the finite element method. This method produces excellent result in predicting formability but seems to having difficulty in predicting springback. Many factors influencing its accuracy cited in the literature [4]. One of them is the material model (or material law) which describes the response of a sheet metal when subjected various stress and strain. A material model comprises a hardening rule and yielding criteria. The hardening rule is dependent of the strain hardening

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exponent 'n' which determine how the material should behave when it is being deformed. The condition on which a material is transformed from elastic to plastic is called the yielding criteria. Many such models have been introduced and each has its own advantage and disadvantage [5]. Hill48 model appears to very popular due to the fact that minimum parameters are required for its implementation. However, choosing the correct material model which incorporated the Bauschinger effect [6] is critically important when dealing with springback. Mixed isotropic and kinematic hardening models are proven to perform exceedingly well [2]. Such models include Lemaitre_Chaboche (L-C) [2], Yoshida-Uemori (Y-U) [6] and Hill48 coupled with isotropic and kinematic hardening rule [7].

The implementation of die compensation is usually via an algorithm. This is achieved by an iterative scheme incorporated in the Finite Element Method (FEM) software. The displacement adjustment (DA) method [8] attempts to minimize the springback error by displacing the geometry of forming shape in the direction opposite to the geometrical error. The algorithm converges when the final result is within the tolerance. In [9] improved this method further in terms of convergence time and accuracy. An alternative robust and automated method proposed by [10] used genetic algorithm in stretch bending of an aluminium alloy. A more recent method for eliminating springback is by hot stamping process where a heated boron steel blank of 900º C is simultaneously stamped and quenched. In spite of this, there are many other parts still require cold stamping.

The concept of design freeze has been widely implemented in many automotive industries with the objective of reducing the risk of costly rework. Once a part design is frozen, it also means no more changes are allowed to take place. In the case of sheet metal stamping part, many times, by the time the tool designer gets involved in the product design cycle, the products specifications are already frozen. This in turn reduces the tool designer's freedom to produce an optimal die structure. In many cases, the availability of simulation tools comes in handy. The die face compensation method has been designed specifically to assist the tool designer in overcoming the effect of springback error. The main objective of this research is to develop a methodology by which springback compensation can be incorporated early in the design freeze stage. The resulted part design is said to be springback-free.

Part Geometry Compensation Method

The conventional method of springback compensation is illustrated in Figure 1a. Die face is iteratively modified via numerical simulation such that the final part geometry is within the desired tolerance of ±0.5mm. The final die face is then used for the actual tool to produce the desired part geometry. On the contrary, the new approach incorporates similar compensation but on the part geometry by adding a series of beads. It is a known fact that beads on part geometry will reduce the effect of springback error. The issue now is to find where to locate those beads. In [11] found that by using the correct bead size and location, springback can be reduced and hence eliminating the need to modify the die face. Their results show that the final part geometry obtained by numerical simulation for a straight rail is within ±0.5mm. An important concept of this approach is that the difficult task of compensation is now transferred to the part designer.

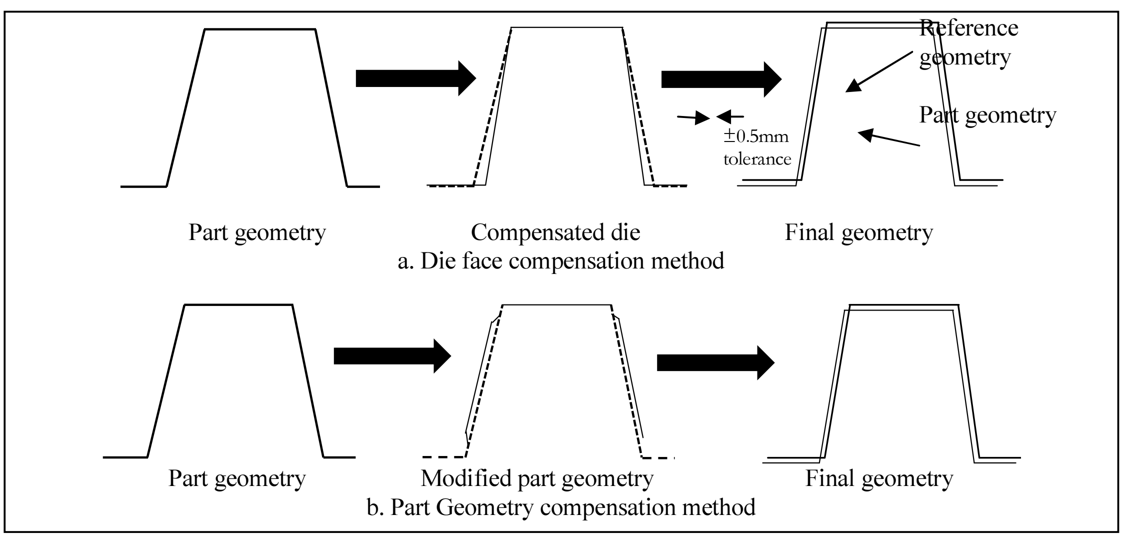


Figure 1: Two types of springback compensation method

Topography Optimization

Topography optimization is a special kind of shape optimization to generate bead pattern on a sheet metal. While it is applicable to 2D shell element, the resulted bead pattern enhances the overall stiffness of the metal part with reduced displacement. Unlike topology or size optimization, topography optimization uses shape as the variable. In this study, the variable used is as shown in Figure 2. The optimization algorithm codes are now available in commercial CAE software. Mathematically, it can be expressed as:

$$\min f(\mathrm{x}) \quad \text{subject to } x_i^L \le x_i \le x_i^U \qquad i = 1, n \tag{1}$$

where x is the design variable and L and U denote upper and lower boundary respectively.

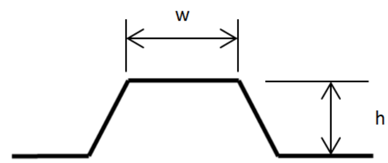


Figure 2: Bead definition

METHODOLOGY

A typical bench mark part geometry s-rail was used to verify the results obtained by [11]. The geometry was subjected to an impact load of 67KN at one end whilst the opposite end was fixed prior to topology optimization using Altair OptiStruct software. This is justified since the geometry in question is part of an automotive frontal structure. Two materials of low (MS) and high yield (HSS) stresses were used to compare the effects of springback errors on similar bead pattern sizes. Table 1 shows the material properties.

Table 1: Material properties of HSS and MS

Material	Yield Strength (MPa)	Young's Modulus (GPa)	Poisson ratio	Lankford Coeff.	Tensile Strength (MPa)
HSS	416	210	0.3	1.152	618
MS	186	210	0.3	1.6	315

The bead patterns generated were then recreated by Computer Aided Design (CAD) software to ensure they do not cling to the punch upon unloading. More importantly, the design should easily be manufactured. Figure 3 compares the bead patterns generated and their interpretation for straight rail and S-rail geometries. Finally, the numerical simulation of formability and springback was performed by Altair Hyperform software with Radioss solver. In view of limited parameters available, a common material law based on anisotropic Hill48 yield function was used. The hardening rule is based on Krupkowski-Swift law [12].

$$\sigma_y = K(\varepsilon_o+\varepsilon_p)^n \tag{2}$$

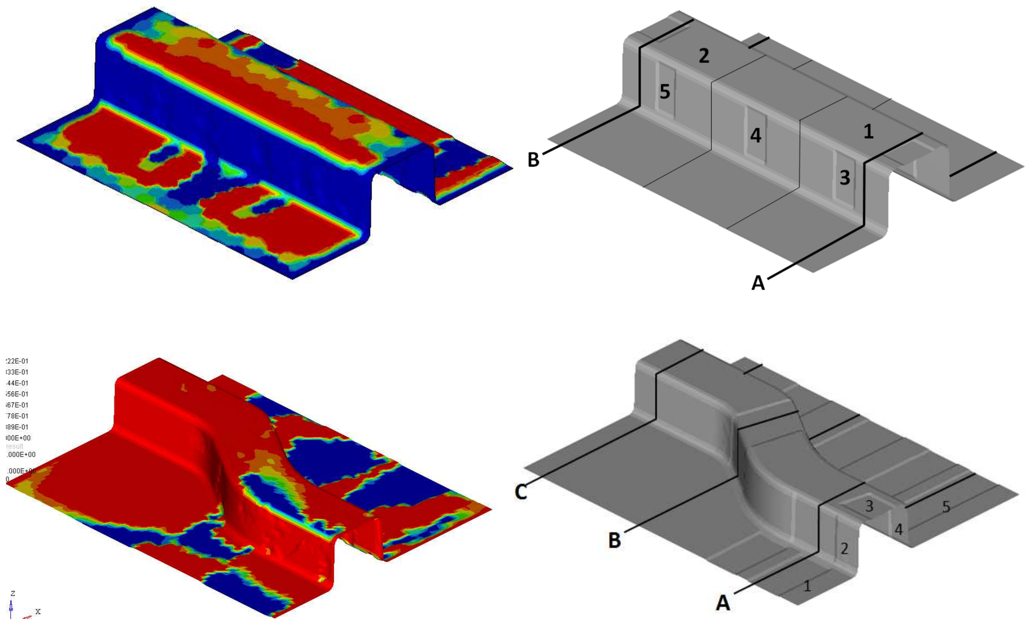
where σ_y is the yield stress, K is the strength coefficient, ε_o is the initial strain and ε_p is the plastic strain. The yield criterion is given by

$$\sigma_{Eq} = \sqrt{(A_1\sigma_{11}2+A_2\sigma_{22}2-A_3\sigma_{11}\sigma_{22}+A_{12}\sigma_{12}2)} \tag{3}$$

where σ_{Eq} is the equivalent Hill's stress, σ_i are the principal stresses. The coefficient, A_i is determined by the Lankford coefficient, r_i as shown as below.

$$R = (r_0+2r_{45}+r_{90})/4 \tag{4}$$
$$H = R/(1+R) \tag{5}$$
$$A_1 = H(1+1/r_0) \tag{6}$$
$$A_2 = H(1+1/r_{90}) \tag{7}$$
$$A_3 = 2H \tag{8}$$
$$A_{12} = 2H(r_{45}+0.5)[1/r_0+1/r_{90}] \tag{9}$$

Maximum springback measured at the cross sections and locations indicated in Figure 3b by superimposing the sprung back geometry against the reference geometry. The normal displacements between the two geometries were recorded.



a. Bead pattern generated by topology b. Interpretation

Figure 3: Bead pattern on straight and s-rail

RESULTS AND DISCUSSION

Table 2 shows the distribution of springback errors at the selected three locations. For material MS, the springback errors are improved by adding beads of 0.5mm to the original S-rail geometry. For material HSS without beads, a maximum error of 1.8mm at the flange is recorded. However, with the addition of 0.5mm dept beads, the overall error is significantly reduced. Increasing the depth to 0.6mm and 0.7mm seem to increase the error slightly.

Table 2: Springback error distribution

Section	A					B					C				
Location	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
MS no beads	0.4	-0.6	0.4	0.5	1.1	-0.1	-0.1	0.1	-0.1	0.3	-0.4	0.6	-0.1	0.5	0.6
MS with beads	0.1	-0.1	-0.1	-0.1	0.5	0.1	-0.1	0.1	-0.2	0.2	-0.1	0.2	-0.2	-0.3	0.3
HSS no beads	0.7	0.8	0.7	-1.1	1.8	-0.8	0.3	0	-0.2	0.4	-0.7	-1.1	-0.5	0.7	0.5
HSS beads 0.5	0.3	-0.3	0.2	0.3	0.4	-0.1	-0.1	0	-0.2	0.1	-0.5	0.5	-0.3	-0.5	0.5
HSS beads 0.6	0.2	-0.8	0.2	0.8	1.2	-0.2	-0.4	0	-0.1	0.1	-0.2	0.2	-0.1	-0.2	-0.1
HSS beads 0.7	0.2	-0.4	0.1	0.3	0.2	0.1	0.1	0	-0.1	0.1	-0.2	0.6	0.2	-0.6	0.3

CONCLUSION AND RECCOMMENDATIONS

We have demonstrated the useful concept of part geometry compensation method. By virtue of numerical simulation, the addition of bead pattern generated by topography optimization has enabled a springback-free part design be implemented by the part designer. In this exercise, it is found that the same bead depth of 0.5m is applicable to both low and high yield stress materials. It is argued that the method may not be suitable for exterior part since the beads are visible by the user. On the other hand, for structural part such as automotive body in white, this approach will be most welcome by the tool designer. The accuracy and reliability of the springback data can further be improved by using the incremental analysis with either L-C or Y-U material model without affecting the original concept. In addition the varying bead depth requirement for different geometry merits another optimization algorithm to be developed. Work is now in progress to validate this concept via experimental data.

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