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Finite Element Simulation for Springback Prediction Compensation

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Abstract — **An accurate modelling of the sheet metal deformations including the springback prediction is one of the key factors in the efficient utilisation of Finite Element Method (FEM) process simulation in industrial application. Assuming that springback can be predicted accurately, there still remains the problem of how to use such results to appear at a suitable die design to produce a target part shape. It is this second step of springback compensation that is addressed in the current work. This paper presents an evaluation of a standard benchmark model defined as Benchmark II of Numisheet 2008, S-channel model with various drawbeads and blank holder force (BHF). The tool geometry modified based on springback calculation for a part to compensate springback. The result shows that the combination of the smooth bead with BHF of 650 kN resulted in the minimum springback and the tool compensation was successfully to accommodate the springback errors.**

***Keywords*— Drawbeads, Springback, Compensation.**

I. Introduction

Springback describes the change in shape of a formed sheet upon removal from the constraint or tooling. It can be considered as a dimensional change which happens during unloading, due to the occurrence of primarily elastic recovery of the material. The quantity of springback can be reduced by imparting plastic stretching during forming, however this can lead to tearing failure. Therefore, the reduction in springback, while also avoiding excessive strain, is important to the success of a sheet metal-forming process. Some approaches to controlling springback have been engaged. Most of them focus on mechanical methods for increasing sheet tension during sheet bending [1]-[4], which considerably reduces the degree of springback.

Assuming that springback can be predicted accurately, there still remains the problem of how to use such results to appear at a suitable die design to produce a target part shape. That is, the springback predictions allow ''forward'' analysis of forming and springback, while a ''backward'' analysis is needed to work from these results back toward an optimized die design. It is this second step of springback compensation that is addressed in the current work.

Two methods for springback compensation are projected in literature, the Displacement Adjustment (DA) method [5] and the Karafillis and Boyce (K&B) methods [6],[7]. The DA method is a strictly geometrical method, to move the surface nodes defining the die surface in the direction opposite to the springback error. The displacement vectors at each node are used to adjust the trial die design until the target part shape is achieved. The K&B method has a more physical approach, based on the internal stresses that cause springback and computing the constraint forces to maintain equilibrium following forming.

In this research, the finite element software used is AutoForm, which is educational license program available

from Advanced Material and Manufacturing Center (AMMC) Universiti Tun Hussein Onn Malaysia (UTHM). The application for AutoForm is for sheet metal forming, in the fields of modeling of tooling geometries, simulation and optimizations of sheet metal process and die surface compensation due to springback errors. The program AutoForm serves as the backbone of the analysis. The overall structure of simulation is shown in Fig 1.

Influences of different parameters on the simulation are blank size and shape, material data, tools, drawbeads, lubrication and process definition. Blank parameters are size, shape, thickness, rolling direction, positions and material data. Material data include of hardening value and choice of appropriate yield surface. Geometric of drawbeads are necessary when hardening and thinning of material drawn by the drawbead into the part geometry has a significant effect on springback.

The rest of this paper is organized as follows. Section 2 describes the analysis procedure which is consists of surface data, material properties, springback prediction and compensation for springback. Section 3 describes the results following by discussion. Finally the conclusion of this work is described in section 4.

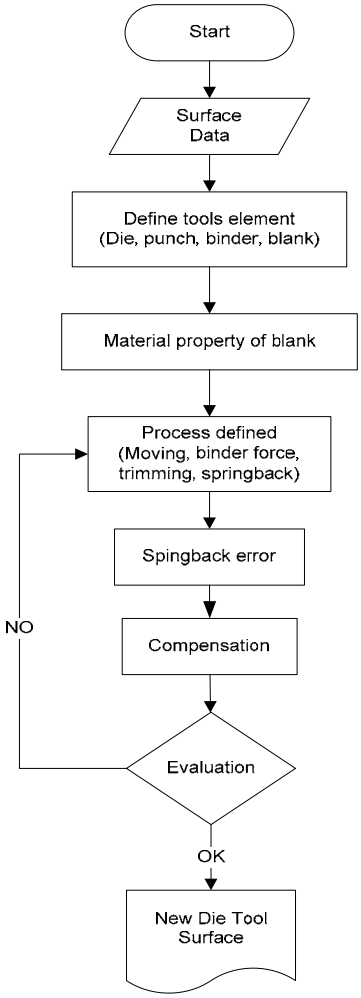


Fig 1. Simulation of die tool surface compensation due to springback error

II. The Analysis Procedure

A. Surface Data

This analysis use S-Rail model of benchmark problem 2 Numisheet 2008. For reasons of S-Rail model, we can use the complete 3D surface data with variation of drawbeads. The models include of punch, die, drawbeads and blank. The drawing and dimensions of S-rail Benchmark 2 model Numisheet 2008 could be seen in Fig. 2.

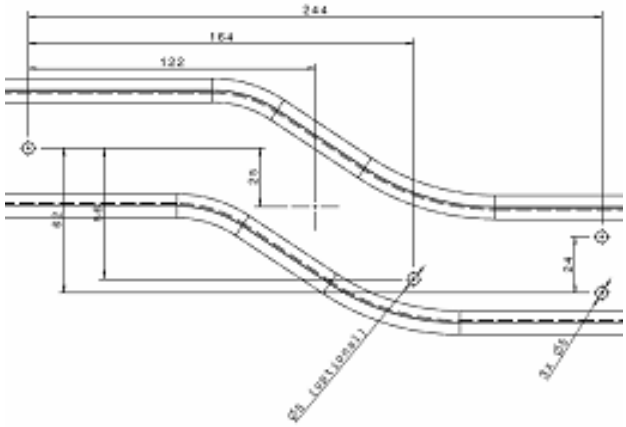


Fig 2. S-Rail model hole dimensions in mm.

B. Material properties

HX260LAD steel sheet is selected as the blank material in our study. This type is micro-alloyed steel grades with high yield strength for cold forming according to DIN EN 10346 / DIN EN 10143. Characteristic of these steels is the minimum and maximum values of yield and tensile strengths and the minimum values of elongation. High strength formable, zinc-iron coated steels manufactured using oxygen blowing process, are aluminum killed sheet steel. Applications of these steels are usually in automotive components, furniture and domestic appliances.

TABLE I
Material Properties

Material type	HX260LAD
Thickness	1.0 mm
Rolling direction	Parallel to global x
Frictional coef.	0.13
Poisson's ratio	0.3
Young's ratio	210 MPa
Yield strength	176 MPa

TABLE II
Chemical Composition of HX260LAD Steel

Element	% by weight
C	0.120
Mn	0.60
P	0.030
S	0.025
Si	0.050
Al	0.015
Nb	0.090
Ti	0.150

The strain hardening of materials in analysis is modeled by anisotropic hardening rule which is widely adopted in

predicting purely elastic springback. Thickness, friction coefficient, yield strength and rolling direction are shown in Table 1. The chemical compositions according to EN 10346 of this sheet are shown in Table 2.

C. Springback Prediction

Until recently, accurate springback prediction was only available for pure bending via empirical handbook rules or simple analysis, and for a few other specialized two-dimensional geometries [8-9]. Usually such results apply to very simple shapes with constant radii of curvature, and are based on well-studied materials such as mild steel.

If a sheet is bent by a moment to a particular curvature, as shown in Fig. 3, and the moment then released, there will be a change in curvature and bend angle. The length of the mid-surface is

$$l = \rho\theta \tag{1}$$

This will remain unchanged during unloading as the stress and strain at the middle surface are zero. From this, we obtain

$$\theta = l\frac{1}{\rho} \tag{2}$$

Differentiating Equation 2, in which l = constant, we obtain

$$\frac{\Delta\theta}{\theta} = \frac{\Delta(1/\rho)}{1/\rho} \tag{3}$$

The assumed stress–strain curve for an elastic, perfectly plastic material that undergoes reverse loading is shown in Fig. 4. From Fig. 4, a change in stress of $\Delta\sigma_1 = -2S$ can occur without the material becoming plastic. Assume that the unloading of the sheet will be an elastic process, than the elastic bending equations can be written in difference form, i.e.

$$\frac{\Delta M}{I} = \frac{\Delta\sigma_1}{y} = \frac{\Delta\sigma_{1max}}{t/2} = E'\Delta\left(\frac{1}{\rho}\right) \tag{4}$$

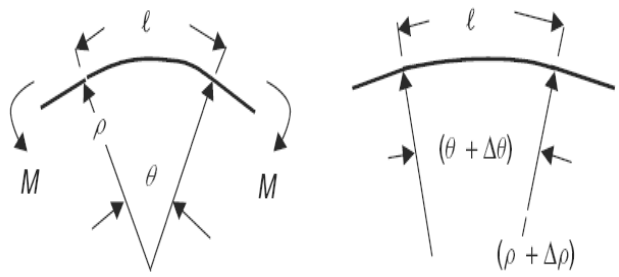


Fig. 3 Unloading a sheet that has been bent by a moment without tension.

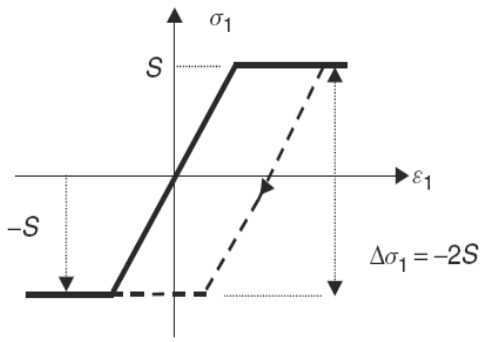


Fig. 4 Elastic, perfectly plastic material model with reverse loading.

For a sheet that has been bent to the fully plastic moment, the unloading curve will be parallel to the elastic loading line as shown in Fig. 5. Noting the similar triangles, we see that for a change in moment of -Mp,

$$\frac{\Delta(1/\rho)}{(1/\rho)_e} = \frac{\Delta M}{M_e} = \frac{-Mp}{M_e} \tag{5}$$

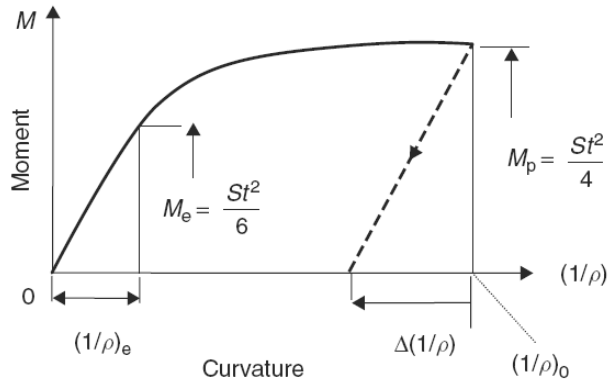


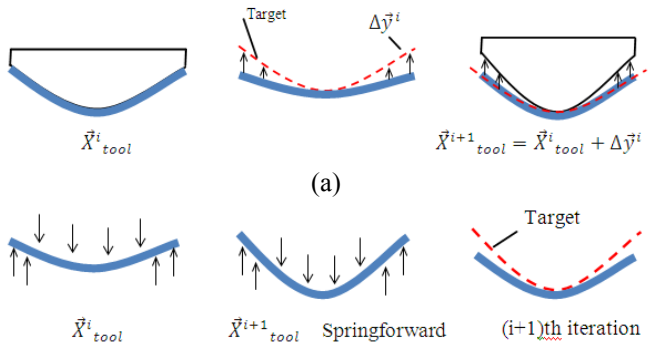
Fig. 5 Moment, curvature diagram for an elastic, perfectly plastic.

D. Compensation for Springback

The approach to automated springback compensation found in the literature is based on an optimization strategy [10]. It involves a gradient method and a sensitivity analysis. This method involves considerable complexity in formulation and implementation as part of a special-purpose finite element program, and thus is not readily implemented with existing analytical tools.

Two methods for springback compensation are the Displacement Adjustment (DA) method and the Karafillis and Boyce (K&B) methods. The flat sheet of metal is deformed to a trial die shape, the trial die shape is same with the target shape at the first step of DA method. The second step is unloading, the springback shape is then compared with its target. The shape error is defined as $\Delta\vec{y}^i$ which is the vector of y coordinates of the target, less the y coordinates of the springback shape for the i th iteration. At the next step, the $\Delta\vec{y}^i$ is added to the current die shape nodal positions, obtaining new tooling shape of $\vec{X}^{i+1}{}_{tool}$. The new die shape is used to deform a flat sheet in the next cycle. Iteration will be conducted until the springback shape within a specified tolerance of the target shape. Fig. 6 shows schematically depicts the DA Method and K&B Method solution process.

The external forces are recorded at the loading process of K&B method. The next step is springforward simulation by applying a virtual inverted stresses. The latest positions are use to creat new die surface based on the part after springback. The accuracy of the die shape is next checked by doing a forming and springback simulation. If the resulting springback shape is not the same as the target, another cycle will be carried out from the first step. Siswanto and Omar applied K&B method successfully minimize the part distortion due to elastic recovery after unloading and creating new finite element mesh for the upper and lower dies by using the automatic mesh generator [11]. Kleinermann and Ponthot [12] used optimization for solving the inverse problem of metal forming for identifying the parameters, particularly the material behavior. The updated model was used for the optimization of initial shape and tool shape.



(b)

Fig 6. (a). Procedure of DA method (b). Procedure of K&B Method

III. Results and Discussion

A. Results of Springback Prediction

The evaluation of springback results will be presented in the following. The simulation results will be compared for each participant as plots on the reference section "a", "b" and "c", as shown in Fig. 7.

Maximum springback errors value on the reference section can be seen in the Table 3. The difference of drawbead design into the part geometry has a significant effect on springback. Application of larger BHF on the process such as 650 and 850 kN provide a lower springback at the tip point of section "a", as shown in Fig.8, but thinning and wrinkling are more probably during sheet metal forming as shown in Fig. 9. The comparisons between springback and the reference geometry of these simulations are described in Fig. 10.

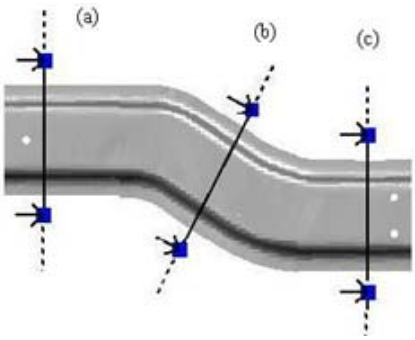
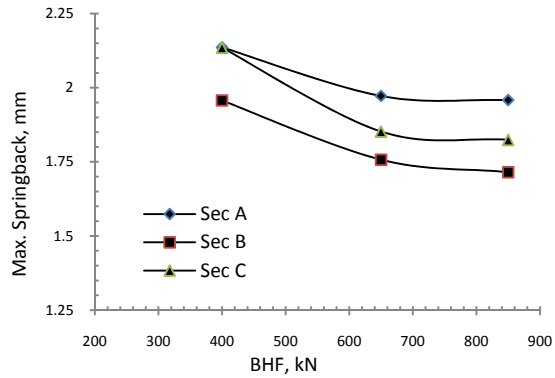


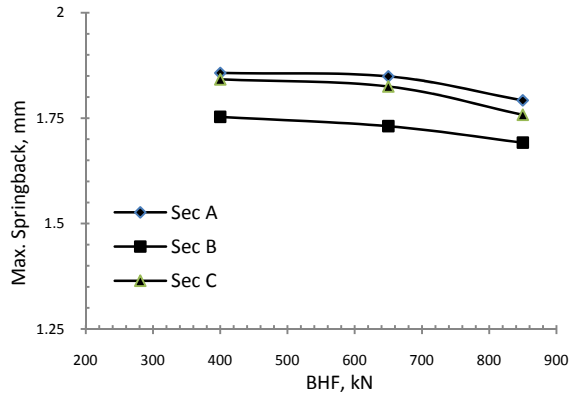
Fig. 7 Springback observations sectioning.

TABLE III
Result of Springback Prediction

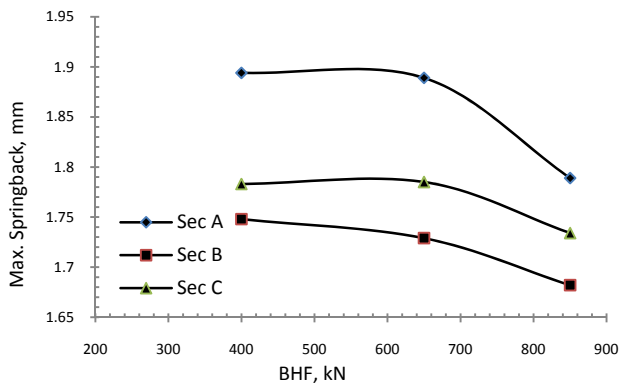
BHF (kN)	Section	Max. Springback (mm)		
		No drawbead	Smooth drawbead	Locking drawbead
400	A	2.136	1.857	1.894
	B	1.957	1.753	1.748
	C	2.135	1.842	1.783
650	A	1.972	1.849	1.889
	B	1.757	1.731	1.729
	C	1.852	1.825	1.785
850	A	1.958	1.792	1.789
	B	1.715	1.692	1.682
	C	1.824	1.758	1.734



(a)



(b)



(c)

Fig. 8 Maximum springback error prediction on section A, B and C, (a) No drawbead, (b) Smooth drawbead and (c) Locking drawbead

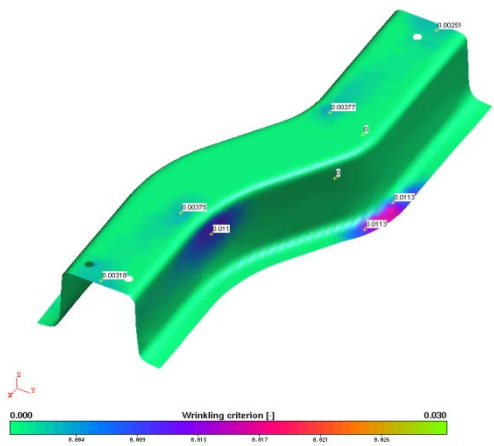


Fig. 9 Highest risk of wrinkling regions in 850 kN BHF

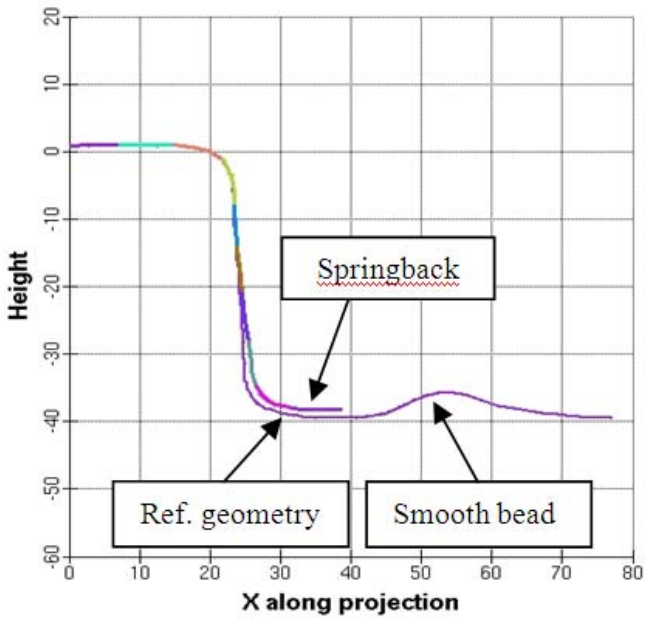


Fig. 10 Measurement springback from reference geometry

B. *Compensation of Springback Prediction*

The reduction of tryout time in the sheet metal forming process is the objective of springback compensation. Free springback is suited for the compensation. The compensation makes sure that the part "springs" into the target geometry without force effect, it can be assumed that it also fits into the measuring fixture.

The reference for the compensation is the formed part before springback. The reference geometry from the springback operation is only used for the comparison of the springback result after the simulation. The forming simulation has to be run with the original part data. Each additional compensation loop depends on the previous compensation, the reference, however, is always the first forming result without compensation. Compensation number will be conducted depend on the value of springback distance in normal direction to the reference geomentry for each position as shown in the Fig. 11.

After each compensation step, the result gets closer to the desired shape. The new surface convert to CATIA file for standard accuracy analysis as shown in Fig. 12, the gaps are < 0.05 mm, the maximum value is 0.065 mm for the process with BHF of 650 kN and smooth drawbead.

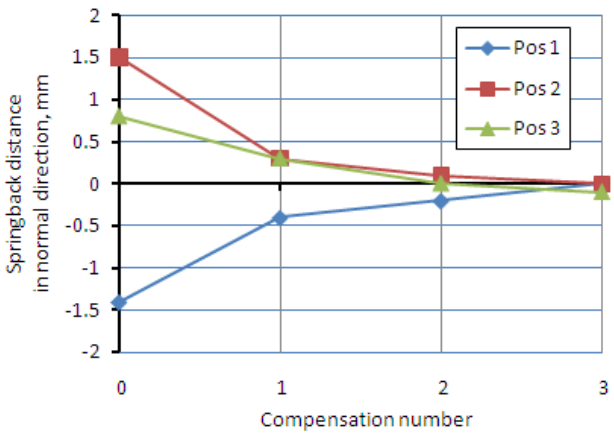


Fig. 11 Compensation number of springback error

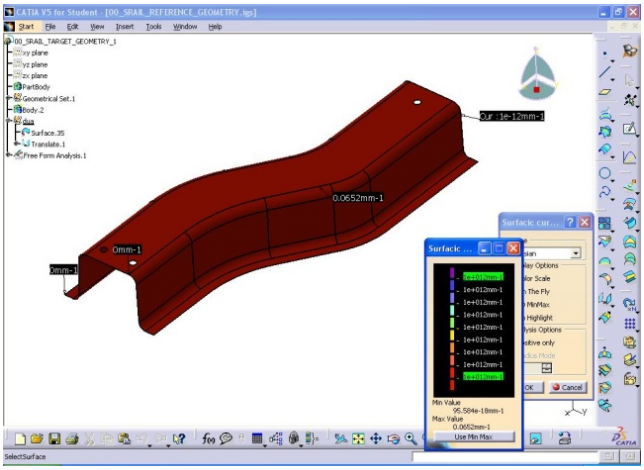


Fig. 12 Standar accuracy analysis in CATIA

IV. Conclusions

The underlying scope of the present work has been to outline a finite element technique for predicting springback deformations compensation in sheet metal forming. In this paper, the influences of drawbeads and BHF have been coupled to analyze the springback error compensation has done successfully.

The critical factor for obtaining robust and accurate solutions in the springback portion of the analysis was the selection of variations of the process parameters in AutoForm. The combination of the smooth bead with the blank holder forces of 650 kN resulted in the best part for this surface model. Although in most industrial simulations virtual drawbeads are used, we expect that most participants will use 3D geometrical models.

Nomenclature

l	Length	mm
M	Moment	Nm
y	Distance	mm
t	Thickness	mm
E	Elastic modulud	GPa
I	Moment inertia	
S	Plane strain yield stress	MPa

Greek letters

θ	Bend angel	deg
ρ	Radius of curvature	mm
σ	Stress	MPa

Subscripts

p	Plastic
e	Elastic

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