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Critical review of variable Young modulus in springback prediction during bending process

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***Abstract*— Parts made from forming process are in huge demand in industries now a day. But while working with formed parts dimensional accuracy is the vital task. Dimensional inaccuracy is one of the main problems while working with the formed part which is due to springback. Springback is elastically driven event in which deform part change in dimension at the time unloading. So for better dimensional accuracy, springback should be predicted. During forming process many parameter are involving and all parameter should be consider for any metal forming analysis. During metal forming young modulus is one of crucial parameter which is change during forming process. Accurate prediction of springback is only possible when variable young modulus is considering. This paper deals with effect of variable young modulus on springback and its prediction model.**

***Keywords*— Variable young modulus, Springback, bending, high strength steel, metal forming**

I. Introduction

High strength steels are increasingly used by industries due to their high strength properties with same weight ratio. Forming of high strength steel is not easy because it is quite difficult to maintain close geometrical tolerance. In addition to that high strength steel has exclusive elastic as well as plastic material behaviour. This exclusive plastic and elastic behaviour makes create more difficulties for engineers and tool designers to control over springback. Springback is the elastically driven event due to which dimensions are changed of formed part when load is removed. Springback is the main responsible factor for dimensional inaccuracy. So it is very crucial for every engineers or tool designer to know such springback value in advance. Apart from this, high strength steel offer high rate of springback compare to that ductile metals, hence it is very much important to control or compensate springback while working with HSS. Due to these reasons it is crucial to predict springback especially while working with high strength steel.

The possibility to predict spring-backs, which is essential for the capability of correcting them, apart from simple bending process, were extremely limited up till now. Using the finite-element method for designing metal sheet forming processes allows for modelling loading as well as unloading process.[1] Most of the springback prediction model considers constant value of young modulus during deformation process. But when it comes to high strength steel or advances high strength steel, such assumption is not true. In fact, during any type of deformation young modulus is change from its original value. But sake of simplicity many of prediction model developed without considering variable young modulus. High strength steel's young modulus is greatly change during deformation process, so, springback prediction model with constant young modulus gives results which are far away from experimental results especially for High strength steel. Hence young modulus is the one of the crucial parameter which should not be avoided while developing a springback prediction model.

II. Springback in Forming Process

Springback prediction model developed by many researchers based on both numerical and analytical approaches. Gardiner [2] reported the pioneer effort with such approach, with some of the additional assumptions,**.** Woo and Marshall [3] derived a springback equation in tension applied during stretch-bending by considering a more universal constitutive equation with work hardening effect. Wang [4] performed the analytical study with considering that, the bending moment disappear as the elastic recovery occurs. Monfort and Bragard [5] extended same process by use of a cantilevered model with a non-uniform moment distribution from the contact point to the outer sheet. Yuen [6] develop analytical model for springback prediction for laminated sheet. This model can be valid for laminated sheet up to n^{th} layer. Springback analysis of layered strip was extended by Hino et al. [7], by investigation of the springback of two-ply sheet metal laminates after being subjected to draw-bending. Hino et al. [7], also concludes that, the springback behavior of laminated strip is gtreatly affected by strength difference between the component layers. R. Narayanasamy and P. Padmanabhan[8] develop regression based mathematical models for the prediction of springback in air bending process of interstitial free (IF) steel sheet. R. Narayanasamy and P. Padmanabhan[8] consider Punch travel *(d)*, strain hardening

exponent *(n)*, punch radius *(r*p*)*, punch velocity *(v*p*)* and width of the sheet *(w)* as an input parameters and springback as output parameter to develop that model. Springback reduction can be studied by Schilp et al[9], by use of simultaneous stretch-bending processes. Osman et al [10], developed springback prediction model for air bending process and results obtained from such model also validated by experimentation.

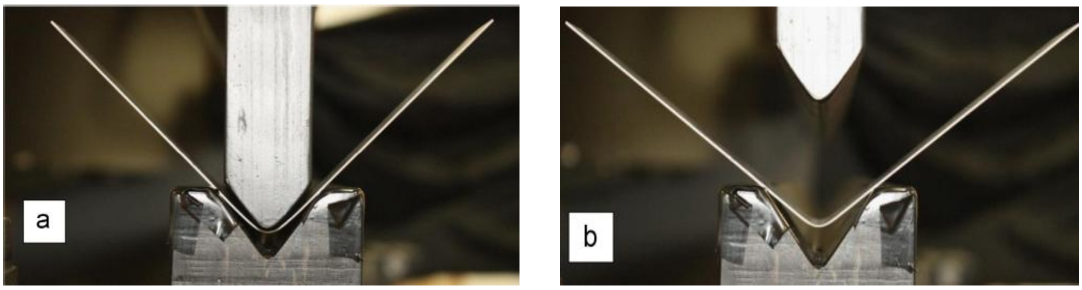

Fig. 1 'speciman before springback(a) and after springback (b) [24]

Moreover, A. H. Gandhi et al. [11] proposed an analytical model for springback of bimetallic sheet in bending and Chintan K. Patel[12] investigates springback behavior of bi-layer sheet during V-bending process. According to Xiao[13], Elastic recovery after unloading causes the redistribution of stresses and the springback phenomenon in which the radius of curvature. R, of any fiber in bending increases to *R* ' after the bending moment is removed. General observation concluded by Xiao[13] with assumption of unloading moment has the same magnitude but opposite sign to the applied bending moment are as follows:

- Springback increases with the yield stress, work hardening and anisotropy, since the higher these values are, the greater the resistance to plastic yielding
- Springback decreases with increasing elastic modulus E because the resistance to elastic bending also increases;
- Bending of a thin sheet with a large bend radius (R), or a large relative bending radius (R/t), increases springback;
- The total springback angle is the sum of springback angles at individual sections dong the bending arc. The longer the bending am, the greater the total springback.

Xiao[13] reported that, The most complex form of springback in sheet forming occurs when the sheet undergoes both bending and unbending deformations. In addition to analytical and numerical investigation of springback, many researchers made their attempt for springback investigation using FEM. Hsu et al.[14] and Lee[15] uses finite element method to predict and investigate springback in different metal forming process. Chan [16] et al. did finite element analysis of springback during v bending process and reported that, the analysis shows that spring-back angle of the valley region decreases with increment of punch radius and punch angle.

III. YOUNG MODULUS

Young modulus is also known as modulus of elasticity, which indicates the value for easiness of material deformation. Initially lames[17] examines the change of elastic modulus with increasing plastic strain According to lames[17] the actual springback was larger than that calculated with a constant Young's modulus value. Still, a constant value of Young's modulus was frequently considered in many FEM codes due to simplicity. Vin et al. [18] consider a basic analytical model to explain the relationship between Young's modulus and plastic deformation based on experimental results. As per Morestin and Boivin[19], the young modulus decreased in the form of piecewise linear function during plastic deformation. Morestin et al. [20], develop kinematic hardening model for springback analysis in sheet metal forming by using elasto plastic formulation. Investigation of the change of elastic modulus by simulating a U-channel forming test using LS-DYNA was done by Yu [21] and compare simulation and experimental springback result. Abdel-Karim [22] concludes that, elastic modulus could have a significant influence on springback prediction under uniaxial stress. They consider the Armstrong-Frederick model and two different values for the young modulus during loading and unloading. The decrease of the Young's Modulus has been related to the presence of an extra microplastic strain produced by the movement of dislocations during the loading and unloading processes. [23]

IV. MATERIAL MODEL WITH CONSTANT YOUNG MODULUS

Wang[25] develop the model to control the springback in press brake. The bent sheet across the arc length is divided in to four zones based on strain in Wang's[25] model. These four zones are plastic zone, elasto-plastic zone, elastic zone and rigid zone.

A. Plastic Zone (O - A):

This is the region where Sheet metal is in contact with the punch tip. In this region, deformation is in pure plastic stage. So, the springback can be neglected in this region.

B. Elasto-plastic Zone (A - E):

A portion of the sheet is in plastic deformation and the rest is in elastic deformation. The elastic recovery of the elastic portion contributes to the springback of the sheet metal.

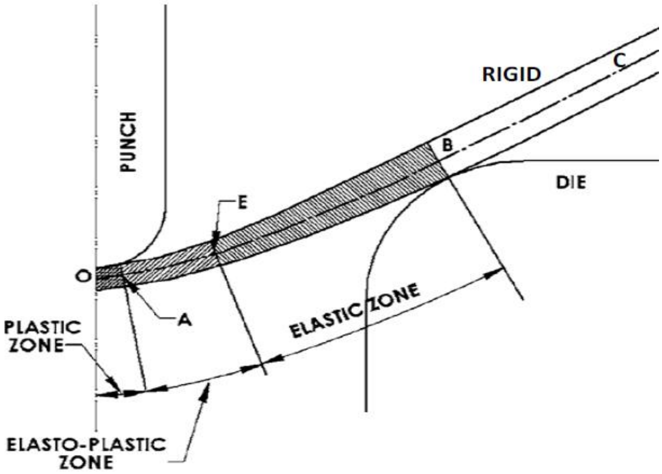

Fig. 2 Deformation zone along the sheet length. [25]

C. Elastic Zone (E - B):

In elastic zone, there is a purly elastic deformation process. The sheet metal deforms elastically and recovers to its original status after unloading. region is very important for the springback calculation.

D. Rigid Zone (B - C):

Tin this zone, the sheet is outside the die corner and there will be no deformation. Thus, calculations for springback not consider this zone.

As per above deformation zone, only elasto-plastic region and elastic region consider for springback phenomenon.

The reduction in curvature after unloading can be calculated by,

$$\frac{1}{r}-\frac{1}{r'}=\frac{M}{E'I} \tag{1}$$

Where $\frac{1}{r}$ is the curvature before springback and $\frac{1}{r'}$ is the curvature after springback, M is the loading moment, E' is the composite young modulus ($=\frac{E}{\left(1-\upsilon^2\right)}$), I is moment of inertia. And springback angle can be expressed as:

$$\Delta\theta_s=\left(\theta-\theta'\right)=\left(\frac{M}{E'I}\right)ds \tag{2}$$

Where θ is initial bending angle and θ' is final bending angle, ds is the length of a small element of sheet.
The maximum loading moment in plastic zone is obtained by the following equation,

$$M_P=\left(\int_{\varepsilon \min}^{-\varepsilon_{e,o}}\sigma_\theta y dy\right)+\left(\int_{\varepsilon_{e,o}}^{\varepsilon \min}\sigma_\theta y dy\right) \tag{3}$$

where y is the location of the fiber along the thickness from unstretched fiber.

The moment along the bent sheet in elasto-plastic and elastic zones is assumed to be linearly decreasing from maximum value at plastic region to zero at the die corner. So the moment can be written as a function of arc length *S*,

$$M(S) = M_P\left(1 - \frac{S}{S_1}\right) \tag{4}$$

where S_1 is the arc length of elasto-plastic and elastic zones. The springback can be calculated by the following equation,

$$\theta_s = \int \frac{M(s)}{E'I} = \frac{M_P}{2E'I}S_1 \tag{5}$$

Although the springback predictions are very accurate, two important assumptions were made in this model:

- Swift's model $\left(\left[\bar{\sigma}\right] = K\left(\varepsilon_0 + \bar{\varepsilon}\right)^n\right)$ was used to describe the sheet metal property.
- The Young's modulus was assumed to be constant during the loading and unloading process. [24]

As per Xi et al. [24] High strength steel and AHSS does not fully satisfy these two assumptions. Constant value of strength coefficient, K, and strain hardening exponent, n, values are not enough to describe the material's behaviour especially in plastic state. Xi et al.[24] develop a new analytical model is developed, which describes the material's property(flow stress) piecewisely and considers Young's modulus variation.

V. MATERIAL MODEL WITH VARIABLE YOUNG MODULUS

High strength steel behaviour is different than that of conventional material, which makes complicated analysis for deformation of such steels. Thus generalised models made for deformation analysis are not valid especially for High strength steel or Adnvance High strength steel. So it is very important to develop a material model which is also true for high strength steel, and this is only possible by considering material parameter during deformation analysis. In actual deformation young modulus is vary from its original value, but most of model developed based on constant young modulus, which makes such model inaccurate. In practical, young modulus is reduce as plastic strain change and thus young modulus is treated as a function of plastic strain in development of material model. According to Vin[18], during deformation, young modulus is reduce maximum up to 84 % from its original value, after this young modulus value is remain constant(Fig.3)

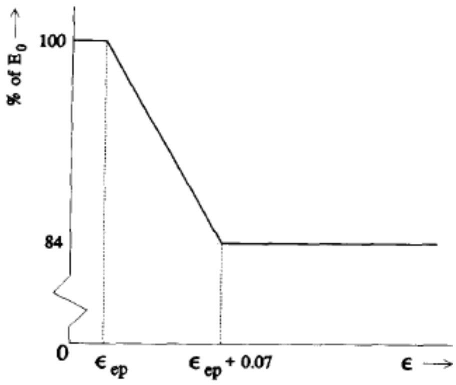

Fig. 3 A Model for change in young modulus during deformation. [18]

For improvement of springback prediction methodology in bending of HSS is to use Young modulus, *K* and *n* values that vary with strain.[24]

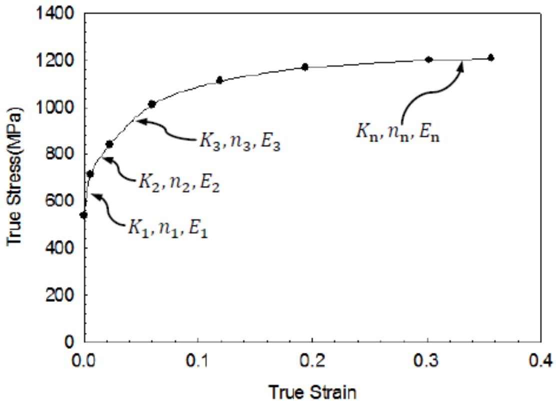

Fig. 4 A Strain division for different values of E, K and n [24]

Steps required to consider variable E during deformation process decided as per [24] are as follow;

- Data related to Young modulus vs. strain obtained from tensile test while bulge test is used for flow stress vs. strain.
- Division of stress-strain curve in to number of small regions as per calculated strain data points.
- Record the data related to variation in Young modulus ,*K* and *n* vs. strain (Fig.4)
- Instead of integrating over the entire domain with one set of constant parameters, the maximum moment, elastic stiffness and springback will be calculated by integrating over each small region with different *K*, *n* and Young's modulus values, in function of strain. The final result is obtained by summing up all the integrals in each region.

A. Loading moment and stiffness variation for bent sheet

As constant Young modulus, in prediction of springback, stiffness can be calculated as *E'I*, where E' is the composite young modulus as discussed by Xi et al.[24], which remains the same through the thickness. But in actual practice, Young modulus for High strength steel is change (decreases with increasing strain), the stiffness has to be estimated again to comprise the effect of young modulus.

By dividing the thickness into small sections, the unloading moment in the plastic section can be written as per Xi et al [24],

$$M_e = w\left(\frac{1}{r}-\frac{1}{r'}\right)\left(\int_0^{y_1} E_1 y^2 dy + \int_{y_1}^{y_2} E_2 y^2 dy + \ldots + \int_{y_p}^{r_{out}} E_p y^2 dy + \int_0^{y_1} E_1 y^2 dy + \int_{y_1}^{y_2} E_2 y^2 dy + \ldots + \int_{y_q}^{r_{in}} E_q y^2 dy\right) \quad (6)$$

$$= w\left(\frac{1}{r}-\frac{1}{r'}\right)(E'I)_P \quad (7)$$

where, $\frac{1}{r}$ is the curvature before springback while $\frac{1}{r'}$ is that after springback and $(E'I)_P$ is the stiffness of the sheet in the plastic zone.

In addition to this, stiffness throughout the length of the bent sheet is not stable. During deformation the strain at outer and inner fiber of the sheet decreases from maximum at plastic zone to zero at the die corner, where at point E which is the boundary of elastic zone, the strain is the elastic limit. Since there is only elastic deformation in elastic zone (E-B), the stiffness in this portion can be calculated using, where maximum elastic modulus. However in elasto-plastic zone, the strains at inner and outer fibers along the bent sheet are different. As a result the stiffness at different cross sections is not constant any more. To solve this problem, a similar method was used here by dividing the arc length into many small regions (1, 2, 3,… n). Again the strain values at the boundaries of each region should correspond to the experimental data points. Then the stiffness of each small section is assumed to be constant and the springback of one region can be calculated using equation $\theta_s = \int \frac{M}{(EI)_n} dS$, where $(EI)_n$ is the stiffness of the given section.

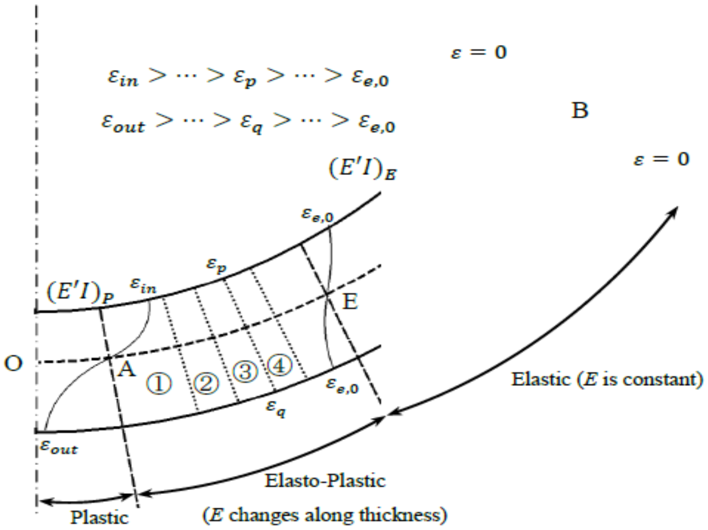

Fig.5. Stiffness variation in bent length. (In elasto-plastic zone, the arc is divided into small regions and the stiffness in each region is assumed to be constant.) [24]

Thus, overall springback of bent sheet is find out by considering all the small sections in the elasto-plastic zone and also in the elastic zone;[24]

$$\theta_s = \int \frac{M}{(EI)} dS = \int_{(1)} \frac{M(S)}{(EI)_1} dS + \int_{(2)} \frac{M(S)}{(EI)_2} dS + ... + \int_{(n)} \frac{M(S)}{(EI)_1} dS + \left(\int_B^E \frac{M(S)}{(E'I)} dS \right) \quad (8)$$

B. The effect of the variable young modulus on the springback

Due to the change of Young's modulus under deformation, the spring-back is larger than the spring-back calculated with a constant value of young modulus.[18] When plastic deformation happens, the change in young modulus can be consider in existing model , as a function of strain. To find out the optimum value of $E'I$, stiifness in this zone divide in to three parts, and final equation in accounted of young modulus is given as per Vin et al.[18] by,

$$E'I = (E'I)_1 + (E'I)_2 + (E'I)_3 \quad (9)$$

$$where,\ (E'I)_1 = \frac{2}{3}(\varepsilon_{ep}.R_m)^3 E'_0$$

$$(E'I)_2 = \left[\left(\frac{2}{2} + \frac{0.32}{0.21}\varepsilon_{ep} \right).\left\{ (y^*)^3 - (\varepsilon_{ep}.R_m)^3 \right\} - \frac{0.32}{0.28R_m}\left\{ (y^*)^4 - (\varepsilon_{ep}.R_m)^4 \right\} \right].E'_0$$

$$(E'I)_3 = \frac{1.68}{3}\left(\frac{S^3}{8} - (y^*)^3 \right).E'_0$$

$$y^* = \min.\left\{ \frac{S}{2}, (0.07 + \varepsilon_{ep}).R_m \right\}$$

During deformation, the bent sheet is divided in to three different zones, and analysis carried out based on characteristic of three zones for evaluation of springback. Equations (1) to (5) are used to calculate springback with constant value of young modulus while Equations (6) to (8) are used to calculate springback with variable young modulus. Equations (1) to (8) were reported by Xi et al.[24] while equation (9) was described by Vin et al[18], which demonstrate effect of variable young modulus on springback.

VI. CONCLUSIONS

Predicted springback value with springback prediction model without considering process parameter is not give the inline result with experimentation results. Inaccurate result leads to dimensional inaccuracy which increases human effort to compensate inaccuracy. So it is very crucial to develop a springback prediction model which gives accurate result especially for high strength steel. Young modulus is the parameter which is continuously change during the deformation process,(i.e. reduce as strain value increase). Thus, accurate prediction only possible for springback when Young modulus variation taken in to account. According to many researchers, results obtained from a model with variable young modulus are in good agreement with practical results. It is obvious that, young modulus is play a vital role during deformation especially in high strength steel, so its influence for metal forming process analysis should not be avoided.

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