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A Review on Springback in Metal Forming

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Abstract

Springback occurs in metal forming after removal of the load due to elastic recovery. It is difficult to develop analytical formulae for spring back and it should be compensated iteratively by for which number of trials are required. Finite element analysis reduces the number of trials reducing the cost, effort and time. In the present paper the review of literature springback and on finite element analysis of spring back is presented.

Key Words: Metal Forming, Finite Element Analysis, Simulations, Springback

It is the dimensional change of the formed part after the pressure of the forming tool has been released. It results from the changes in strain produced by elastic recovery. During sheet metal forming processes such as stamping and deep drawing where bending/unbending is predominant, the region around the neutral plane in the material undergoes both elastic and plastic deformation. When the punch has reached the final draw depth and is removed, the elastic strain in the material is recovered, which produces springback in the part due to this nonuniform stress distribution in the sheet. The discrepancy of shapes between a deep drawn product and the designed one due to springback must be compensated for, at the tool design stage in order to guarantee its function and assembly with other parts. It is, however, so difficult to predict and estimate the amount of compensation for springback that tool modification relies on the experience or a trial-and-error procedure in the press shop. This compensation procedure requires extra try-out time, which increases the cost for the tooling and product development time. Partnership for a New Generation of Vehicles (PNGV), a wing of the United States Council for Automotive Research (USCAR), identified sixteen manufacturing technologies that need to be addressed in order to improve automotive manufacturing [1] The ‘‘springback challenge,’’ is one of these crucial manufacturing areas. In a forming process such as deep drawing, it remains to this day one of the great challenges and one of the greatest problems for the manufacturer. The preferred use of high-strength materials such as dual phase steels in many modern manufacturing processes aggravates the problem of increased springback.

Springback is however affected by the complex combination of bending, unbending, and stretching imposed on parts during deep drawing process. Therefore, the proper understanding of the effects of process parameters as well as material properties on springback is so useful to effectively design the processes.

The magnitude of springback depends on the bending moment, which intern depends on the through thickness stress distribution at each point in the plane of the sheet at the end of the drawing operation. The accuracy of springback prediction depends on the development of the internal stress distribution through out the drawing operation, which makes it sensitive to a range of variables.

Parametric studies were carried out experimentally [2-5], numerically [6-8] and Analytically [9-22]. One of the experimental tests is draw/bend test [23] as shown in Fig. 1. It consists of two hydraulic actuators oriented at a 90^0 angle, and a fixed or rolling cylinder to simulate a tooling radius over which the strip sample of 50mm wide is drawn. The upper actuator is programmed to provide a constant restraining force, F_b. The lower actuator is set to displace at a constant speed, v, thus drawing, bending, unbending, and possibly stretching the sample over the cylinder. In this case, the sheet metal strip undergoes bending and unbending under constant tension, resulting in a load reversal in the material. At the end of the test, the sample is allowed to springback by the removal of the specimen from the grips and the springback angle Δθ is measured. As such, it is exemplary for a number of sheet forming operations, but has the advantage of simplicity. More importantly, sheet loading may be controlled directly and accurately, since in real press forming operations, sheet loading depends on the complex interaction between the material behavior, contact and friction, draw-bead configurations, as well as blank holder forces and displacements

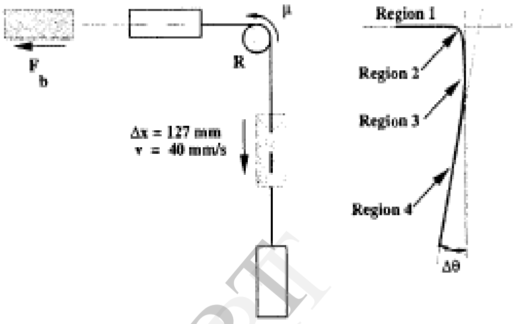

Fig.1 Schematic draw bend test and unloaded specimen shape after bending

Another test used to find out springback is U bend channel test as shown in Fig. 2. In this test a channel is drawn from a rectangular blank. Springback error is studied after removal of the load. Number of authors [25-26] have simulated the draw-bending test as a well characterized forming operation that produces springback similarly to industrial stamping forming operations.

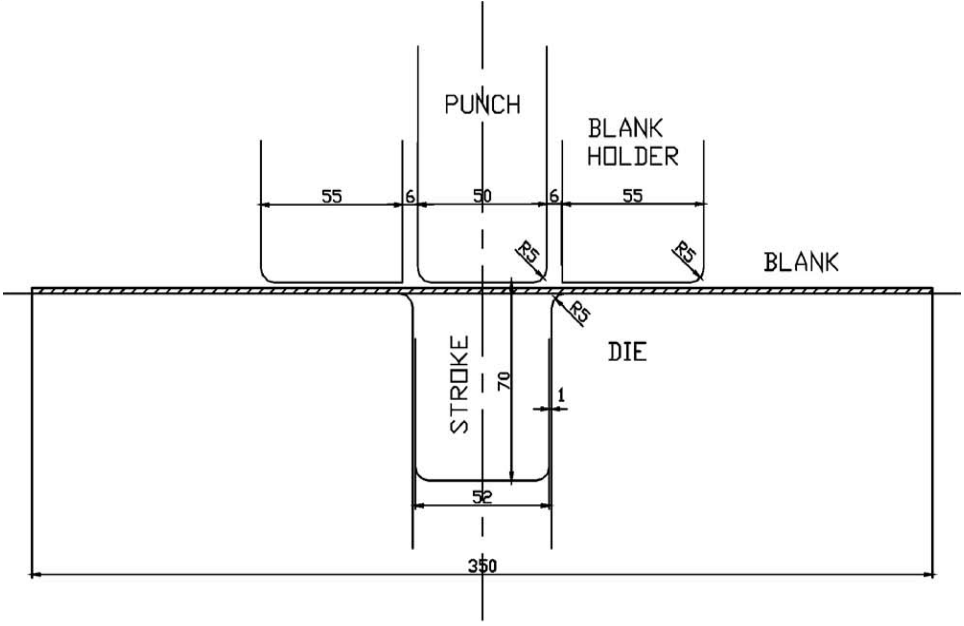

Fig 2. Schematic diagram of U bend channel test

Although the above two tests are preferred in understanding certain aspects of springback, they are not close enough to deep drawing operations usually found in automotive stamping operations. To simulate the deep drawing process more closely split-ring test was proposed by Demeri et al. [27,28] . In this process, a cylindrical cup is deep drawn and then cut into several closed rings. These are then split open perpendicular to the circumference of the ring. This results in the release of energy stored in the material during deep-drawing and residual stress development, leading to springback. The extent of ring opening indicates the amount of the springback. However cutting and splitting of the rings with out induction of residual stresses especially in case of thin walled cups is a difficult task. Deformation analysis of this test has been presented by Cedric et.al.[29].

The classical analytical approach assumes simple tool description and material properties. Examples of this approach include the springback analysis of pure bending with elasto-perfect plasticity [30], plane strain pure bending [31] plane strain bending [32,33], plane stress bending [34] with additional tensile force, and biaxial elastic-plastic pure bending of a rectangular plate [35] and beam [36]. The analysis of process effects was mainly performed for 2D draw forming, which involves the die corner and sidewall curl regions. Jeunechamps et al. developed a closed form method to predict springback in creep age-forming and investigated the effects of geometric parameters on springback of aluminum plates. Wang [38] conducted the analytical study by assuming that the bending moment vanishes as the elastic recovery occurs. Monfort and Bragard [20] extended this procedure by using a cantilevered model with a nonuniform moment distribution from the contact point to the outer sheet. Cao et al. [21] proposed a linear moment distribution in the contact area and that model compares favorably with the experimental results of Liu [22]. The major difficulty with the analytical solution is due to the lack of understanding of the stress distribution throughout the sheet, which limits the analytical approach to simple geometries and simple deformation. It only provides a useful basis for the qualitative understanding of process and property effects on springback. Hence, Numerical methods are needed for more complicated cases.

With the rapid development of computational power and solution techniques, the finite element method has been widely utilized to predict and understand the springback. Examples of the FEM springback analysis of 2D formed parts include the cantilever beam analysis by Kawaguchi et al. [30], the 2D draw bending benchmark problem by Mattiasson et al. [31] and He and Wagoner [23]. In addition, the increased availability of commercial programs for the simulation of forming processes like LS-DYNA, PAM-STAMP, AutoForm, DYNAform, Stampack, has greatly facilitated the numerical simulation of springback. In combination with experimental work, such approaches and programs have been utilized for predicting springback after simple forming operations, e.g., cylindrical tool bending [39], flanging [40],V-die bending [41-43] and U-channel forming [44].

There was also considerable research in the area of the establishment of the possible influence of algorithmic and numerical aspects of the simulation on the corresponding results. These include the material model [45-47], the integration scheme [48-50], the element type [51], process conditions [52-53], and the solution procedure [54-56]. To this end, relatively simple forming processes such as draw-bending or deep drawing of a cylindrical cup are utilized.

A typical springback simulation consists mainly of two parts: The deep drawing process followed by the computation of the elastic springback. The deep drawing part is highly developed and yields reliable results. Numerical examples have shown that the computation of elastic springback based on explicit finite element codes may yield unreliable results. On the other hand, the analysis with implicit codes is more reliable but in terms of computer resources more demanding. Usually, low order shell-elements yielding an algebraic rate of convergence are applied. The *p*-version of the finite element method is also tried for computing efficient and reliable approximations of the elastic springback [57]. In some of the approaches, the deep drawing part is computed with a commercial h-version code, while the geometrically non-linear elastic springback is computed with the p-version of the finite element method. Many simplified approaches have been proposed in simulation and design of the metal forming process.

Li et al. [44] investigated the springback of draw bend tests including parametric studies on numerical and physical parameters such as the size of meshes, the number of integration points, tool radius, and restraining forces. Geng and Wagoner [39] analyzed springback angles and the role of anticlastic curvature especially with large restraining back forces using a series of simulated draw bending tests in conjunction with an anisotropic hardening rule and four different yield functions. In particular, bending and unbending represent a loading path change of the load-reversal type in which isotropic and kinematic hardening are the principle hardening mechanisms. More complicated loading paths arise during processes such as deep drawing of closed structures. Chung et al. [51] and Lee et al. [52-53] evaluated the springback of a modified automotive part by implementing the modified combined isotropic-kinematic hardening and nonquadratic anisotropic yield function. One major trend in metal forming simulation is to ignore the elastic deformation of the structure compared to the plastic part. For the elastic springback the constitutive relation that considers the elastic and plastic parts together has to be used. The advantages of the FEM method over analytical methods are its capabilities to model complicated tool descriptions and realistic constitutive behavior.

Various measures are developed for the quantification of springback. In case of channel forming it can be defined with the angle springback of the corner bends and side wall curl (Fig 3). Angle springback is the change in the final bend angle after the blank undergoes bending by release of elastic component of bending movement. Where a side wall curl is a result of blank bent and then unbent under tension while passing over a die radius, which causes the affected area to curl due to release of residual bending movement.

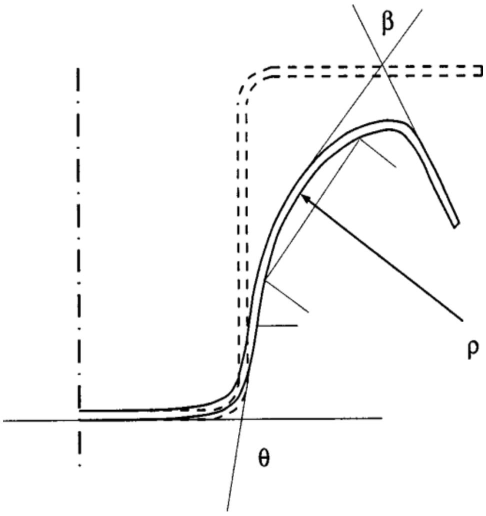

Fig. 1.11 Variables used to measure the springback in ‘U’ bend test

For this test Lee and Yang [42] described springback error in terms of angles ‘θ’ and ‘β’ and side wall curvature ‘ρ’, where as Kim and Thomson [54] described in terms of ‘θ’and ‘ρ’ only. But these are hard to measure precisely, because it is difficult to determine where the wall curvature begins. Moreover using angles and the radius of curvature is only useful for U bend test. Webb and Hardt [55] developed shape error measure using Discrete Fourier Transforms (DFT) for their iterative die design. The coefficients of DFT decription of shape is able to reduce the dimensionality of die design down to a small set of values that is much easier to manipulate. Fourier models, however, suffer the problem that discontinuities such as corners or edges are difficult to describe unless some smoothing is done to the surface that is being modeled. Karafillis and Boyce [56] used root mean square (RMS) of the vertical distances between the desired shape and actual shape as the shape error measure. The RMS error does not give any indication of shape error. However, it can be used for comparison. Kase et.al [57-58] used differential geometry to determine the principle curvature differences between the desired and actual shapes to calculate the local shape error of the component. The changes in the principle curvature calculated on the sample on the surface of the component are divided into mount, valley and twist. The global shape error is calculated using the average surface normals on arbitrarily defined patches of the component for both the desired and actual shapes. These normals are used to determine the global shape error by considering the bent angle and twist angle between the two shapes' average normal vectors. The advantage with this method is that the surfaces to be compared do not need to be aligned. As the case of Fourier models the surfaces of the shapes need smoothing if there are discontinuities before the shape error description is utilized. B.F. Rolfee et.al [59] used point distribution model (PDM) to measure springback by comparing an artificially created non springback shape to the formed shape that has inherent springback.

Research has been carried out to find out the effect of various material, process and tooling parameters such as material properties, sheet thickness, friction condition, binder force, and tooling geometry, etc on the springback. The relationships that exist between springback and these parameters are extremely nonlinear with multiple interactions. It is observed that the springback is greater, the higher the yield stress, the lower the elastic modulus, and the greater the plastic strain. For a given material and strain the springback increases with the ratio between the lateral dimensions of the sheet and its thickness. B.F.Rolfe et.al [59] have studied the effect of blank holder force die corner radius and clearance from the U bend tests. They found die radius and tool gap directly effect the final geometry of the channel. These two parameters are not independent in particular with the springback and side wall curl effects. The flange angle springback appears to decrease by increasing the blank holder force and die radii. The floor angle springback is decreased by increasing the blank holder force. The floor angle springback is increased by increasing the combination of die radii and clearance. The error in the flange length is decreased when the blank holder force or the clearance is increased, and the error in the flange length is increased when the die radii is increased. The extended flange length shows decrease in error as the blank holder force or die radii is increased. In total they concluded that springback error decreases with the increase of blank holder force or increase of die corner radius and there is no consistency in the results given by clearance. Kim and Thomson [54] have also suggested that the clearance has very small influence on the angle springback and side wall curl. But in the flanging process it found that springback decreases as the die corner radius decreases, the gap to thickness ratio decreases, the binder force increases, and the punch nose radius decreases. However, the punch nose radius has an influence on springback within a relatively narrow range, i.e. it has less influence at a larger nose radius [60]. From the above it is observed that the effect of parameters on the springback varies from test to test. So the U bend channel test or draw bend test may not be truly representing the springback behavior in deep drawing process where the state of stress is entirely different than the above two.

Many researchers have tried to compensate the springback by various means. Lagrangian approaches of Design Sensitivity Analysis (DSA) in large deformation elastoplasticity were proposed by Badrinarayanan and Zabaras[62] and Wiechmann and Barthold [61]. However, they did not bring design capability of minimizing elastic springback. Guo et al.[63] proposed an inverse approach to optimize the sheet metal forming parts. However, they used a path-independent material model, which is only valid for the loading process. Because material is path independent, they developed an adjoint variable method for design sensitivity analysis, which is not applicable for the path-dependent material. Karafillis and Boyce proposed an inverse springback calculation method to obtain the desired workpiece geometry after springback. They determined the shape of the tool based on the force that is required to springforward the work piece. In the case of the vertical deep drawing, however, the springforward method would not work because the vertical part of the punch cannot exceed more than 90 deg. Gan and Wagoner [64] suggested a die design scheme with a displacement adjustment method to compensate for springback. Chou and Hung [65] optimized values of die gap and punch radius with the response surface method in channel wall bending. Liu et al. [66] adopted the variable blank holding force in order to reduce springback and Kim and Huh [67] introduced the optimization procedure for the blank holding force with a direct differentiation approach in the U-draw bending process. Palaniswamy et al. [68] determined the optimum blank dimension by using a design sensitivity analysis in order to compensate for springback in the flexible forming process.

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