FINITE ELEMENT ANALYSIS OF SPRINGBACK PROCESS IN SHEET METAL FORMIMG

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ABSTRACT: Springback prediction is essential to ensure the economics of sheet metal forming operations. To achieve accurate results, current nonlinear recovery applications in finite element (FE) analysis have become more complicated and therefore require complex computational programming work to develop a constitutive model. At the end of a plastic deformation and after the load is released from the sheet metal, the change of stress in the elastic area becomes nonlinear. The change of elastic modulus is influenced by the amount of plastic strain, yield locus size, and stress normalization point. The effects of nonlinear recovery on the residual stress distribution and the sheet metal final shape after springback were investigated. The analysis results show that the formed hysteresis loops due to the unloading and reloading process were able to be simulated successfully by the proposed method. It was found that the distribution of non-zero residual stresses at the end of springback process was highly related to the nonlinear recovery curve.

KEYWORDS: *Nonlinear recovery, springback, sheet metal*

1.0 INTRODUCTION

Sheet metal forming has been used extensively in the packaging and home appliances industries. Although the process has been adopted for the last few decades, the knowledge about the entire process has yet to be fully mastered. This has resulted in a trial-and-error procedure, which involves a lot of time and costs to ensure that the resultant product meets the desired design. A poor comprehension of the sheet metal forming process is also the reason why a handful of industries are focusing their attention on simpler forming processes that are geared towards the use of new materials and new production processes such as hydroforming and incremental forming [1].

One of the problems encountered in the sheet metal forming process is the phenomenon of springback. In the forming process, the sheet obtained at the end of the process resembles the geometry of the tool involved. Once all the force is released, the metal sheet experiences springback. Generally, the springback of sheet metal is due to elastic recovery [2]. Although the elastic recovery at the location involved is small, it can produce significant deformation due to the mechanical reproduction at a different location where bending and/or curved surfaces are involved. This springback phenomenon affects the quality of the product and makes it more difficult to assemble the product.

Finite element (FE) analysis of springback is highly related to the elastoplastic constitutive modeling, where the Young's modulus is often regarded as a constant, even after undergoing plastic formation. However, several experimental observations have indicated that metallic materials, including steel and aluminium alloys, differ in linearity, i.e. they form hysteretic loops during unloading and reloading [3], [4]. This relationship is known as nonlinear elastic recovery. However, in FE analysis, after plastic formation, the unloading process begins based on the initial elastic modulus that represents the linear elastic recovery.

Sheet metal material properties are obtained in mechanical tests such as the tension-compression test. If the sheet metal undergoing cyclic loadings, the flow curve will be in the form of a closed loop. The width of this loop increases with an increase in the plastic strain during the plastic forming process, where the area of the loop represents the amount of dissipated work. Compared to a monotonic flow curve, the plastic behaviour as a whole is not affected by the loading and unloading cycles [5], [6]. Govik et al. [7] mapped the instantaneous tangent modulus to illustrate more clearly the nonlinear nature of the unloading. The researchers discovered that there is no part on the unloading curve that is linear in nature. At the same time, for a pre-strain higher than two percent, the nonlinear nature is the same between one another, while the elastic modulus decreases with the increasing pre-strain. This prompted other researchers to develop modelling methods in FE software to obtain simulations that mimic the behaviour of actual materials [2]–[4], [8]. However, due to the complexity of reproducing the models, the variable linear elastic modulus achieves a relatively wider range of application in springback prediction [9].

The objective of this paper was to examine the effect of considering the nonlinear elastic recovery in FE analysis of springback with a constitutive model developed in the previous work using artificial neural network approach [10]. In addition, the simulation results were analyzed to recognize the behavior of anticlastic curvature that affected the springback simulation.

2.0 METHODOLOGY

This study utilized the experimental data that have been published by a study [11]. The published data were chosen based on their comprehensiveness in providing information from the identification of material parameters until the measurements of springback. Figure 1 shows the tensile test results for a DP980 steel sheet with intermediate unloading cycles. Due to the nonlinear unloading and reloading behavior, hysteresis loops were formed. These loops were noticeable significantly as the flow stresses increased prior to unloading.

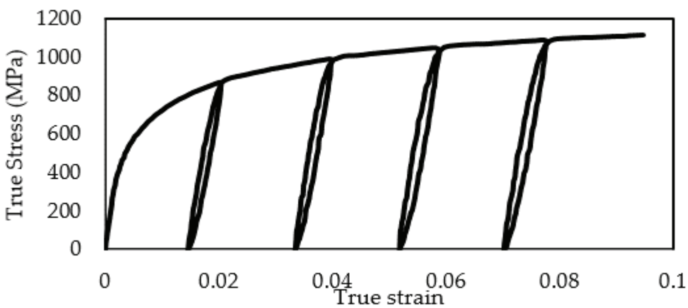

Figure 1: Tensile test result for DP 980 steel with intermediate unloading cycles [11]

A constitutive model that represents the nonlinear recovery has been developed in a previous study [10]. The developed model was then utilized in the simulations of the draw-bend springback test based on the experimental works [11]. The published experimental work was chosen based on its capability to represent a wide range of sheet metal forming operations while also had the advantage of simplicity and a controllable sheet tension force. Figure. 2 shows a schematic of the draw-bend test that was utilized to mimic the mechanics in sheet metal forming, which consisted of drawing, tensioning, bending, and straightening when passing over the die radius. The strip with thickness of 1.43 mm was cut to a width of 25 mm along the rolling direction, and lubricated with stamping lubricant. There were two hydraulic actuators (upper & lower) oriented at 90º to each other and a rotating cylinder with a radius of 6.4 mm which was located at the action line intersection. The purpose of the rotating cylinder was to simulate the radius of the die where the strip would go through the drawing process. The upper actuator was used to generate a constant controlled force or back force, whereas the lower actuator was displaced at a constant velocity to draw the strip through the rotating cylinder. The drawing process started when the lower actuator was displaced to 127 mm at a velocity of 25.4 mm/s. At the same time, the upper actuator was applied with back force which was set to be 30 to 80% from the 0.2% offset of the yield strength. At the end of the drawing process, the strip was released from the grippers and fixtures to allow springback of the drawn strip.

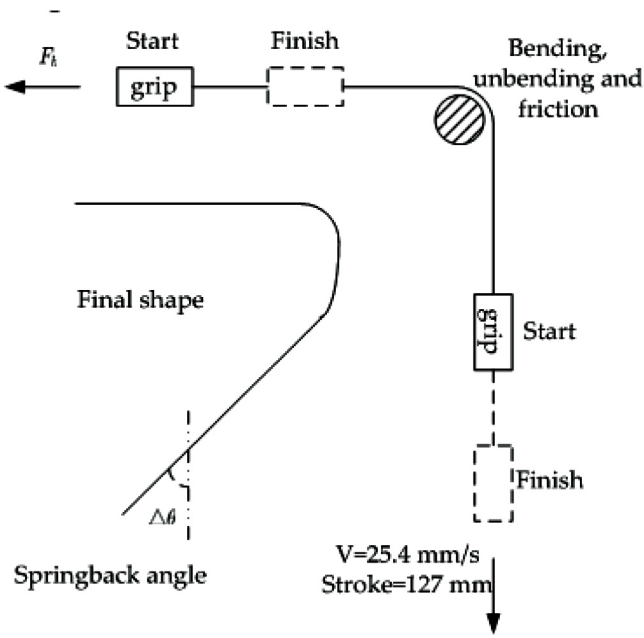

Figure 2: Schematic of the draw-bend springback test [11]

The draw-bend springback test simulation used a three-dimensional FE model with an implicit solver for the bending, drawing, and springback steps as shown in Figure 3. In the simulation, the modulus of elasticity and poisson ratio were 208 GPa and 0.291 respectively. The plastic deformation process (hardening) was assumed to be isotropic and the plastic modulus was generated based on a monotonic curve as shown in Figure 1. The coefficient of friction between the strip surface and the rotating cylinder was set to be 0.04 in the simulation.

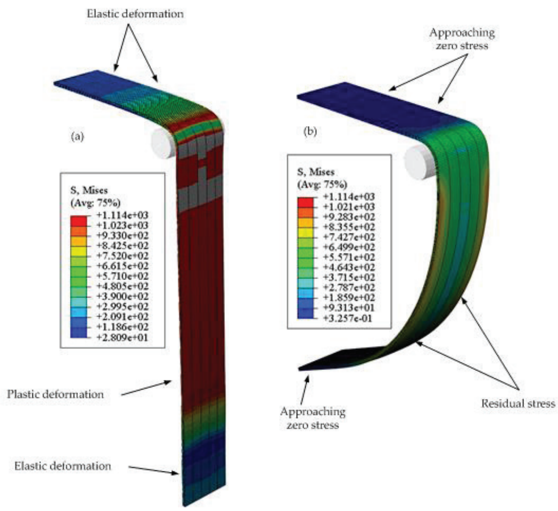

Figure 3: Mises stress distribution; (a) before and (b) after springback

3.0 RESULTS AND DISCUSSION

In each simulation, after the load was being released, the elastic modulus was updated at every increment to create the nonlinear recovery condition based on the amount of plastic strain and true stress before unloading. By utilizing the information of plastic strain and true stress, the constitutive model was independent from the type of material as well as the geometry of the material such as blank thickness. The draw-bend simulation results were evaluated at every back force level and the profile of each test was plotted in Figure 4. It was observed that the springback value decreased with the increasing of back force. This is due to the influence of back force to the material's tension in reducing the springback angle. The influence can be understood by referring to the stress-strain profile produced from the whole simulation in Figure 5, where the stress-strain value represented the profile of one single element of the sheet metal blank in the draw-bend test. The fluctuating tension and compression were explained in a schematic of stress variation in the sheet metal blank, as shown in Figure 6. In the initial step of draw-bending, sheet metal blank would experience elastic deformation before passing through the rotating cylinder. Through the drawing process, the blank experienced bending and plastic deformation at the rotating cylinder. After passing through the rotating cylinder, the element in the blank experienced unbending due the blank straightening. At the end of the drawing process, the load on the blank was released to let the springback to occur where the stress of each element reduced elastically. From Figure 5, the final stress points were not reduced to zero stress but remained as residual stress. Therefore, it is important to include nonlinear elastic recovery in springback simulation to achieve accurate results compared to the usage of linear elastic recovery. Although the difference of stress between the linearity was small for each element, the mechanical reproduction of every element in the blank produced significant impact in final springback angle.

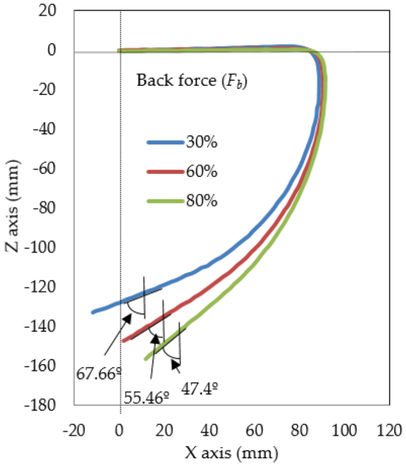

Figure 4: Simulation of draw-bend test

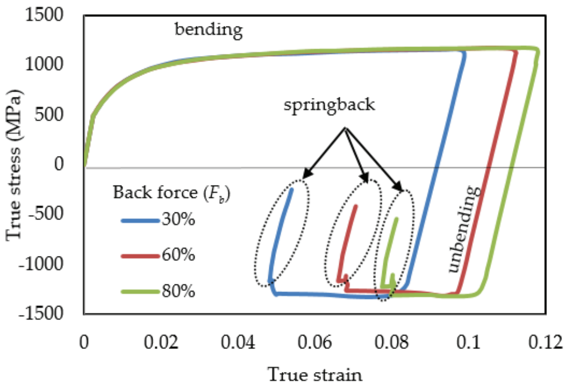

Figure 5: Variation of stress value in the draw-bend test simulation

The reduction of springback angle due to the increasing of back force was related to the formation of anticlastic curvature as shown in Figure 7. It was a secondary curvature that was orthogonal to the primary curvature, which could be viewed from the blank width direction. The anticlastic curvature was directly proportional to the back force compared to the springback angle as shown in Figure 8. The curvature increased the moment of inertia significantly, thus, reducing the springback angle.

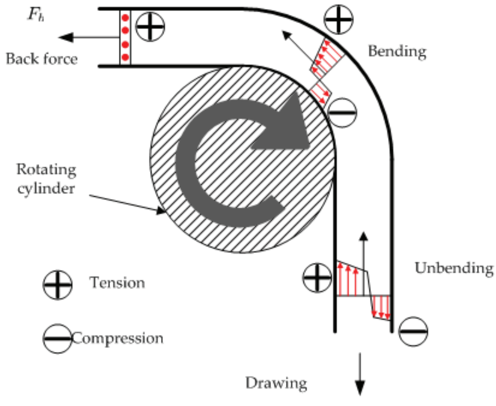

Figure 6: Schematic of stress variation in the sheet metal blank

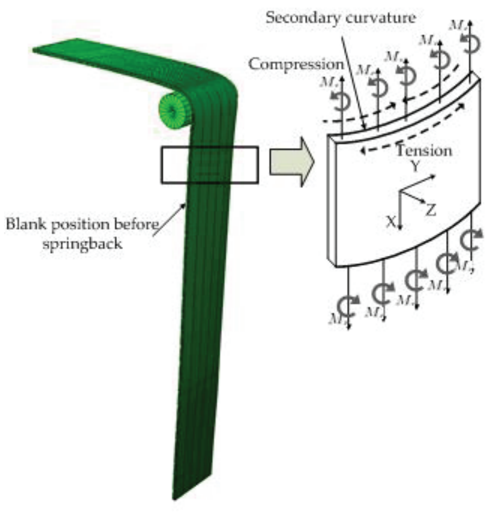

Figure 7: Anticlastic curvature formation in draw-bend simulation

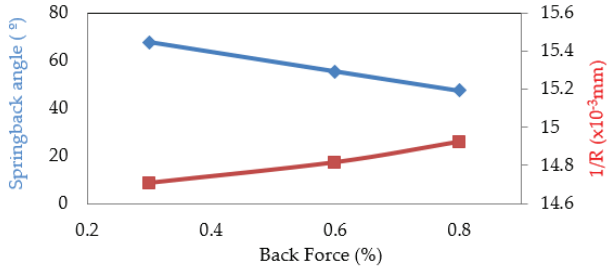

Figure 8: The effect of back force to the springback angle and anticlastic curvature

4.0 CONCLUSION

In this paper, a draw-bend test simulation is described and the results obtained are used for comparison to understand the springback occurrence in sheet metal forming. Implementing nonlinear recovery is important in finite element simulation of sheet metal forming in order to achieve accurate amount of strain with the subjected stress due to the existence of residual stress at the end of the springback process. It is found that the springback angle reduces with the increment of back force due to the formation of anticlastic curvature. This shows that there is a need to balance the level of primary curvature or springback, and the secondary or anticlastic curvature in order to produce sheet metal product that is close to the actual design.

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