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Modelling and sensitivity analysis of twist springback in deep drawing of dual-phase steel

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ABSTRACT

Twist springback induced by unbalance elastic deformation and residual stresses in a sheet after a forming is of particular importance and complexity. The twist springback can be influenced by several factors, such as blank shape geometry, material anisotropy and sheet piercing. A sensitivity study of these parameters provides insight into the twist springback control of rail parts. In the present work, a more reasonable evaluation of twist springback of a long member with respect to the central principal inertia axes of the longitudinal cross-section was proposed. In order to explore the source of twist springback, the analysis of the relationship between torsion moment and twist angle was introduced. Mechanical tests including uniaxial tension, forward-reverse shear and hydraulic bulge tests were conducted to determine the material constitutive parameters of a DP500 steel. Several key modelling techniques including the friction coefficient identification and digital image correlation were performed for improving the robustness of twist springback prediction of a typical design benchmark of a curved rail channel formed by deep drawing. Finally, the sensitivity of the constitutive model, material direction and blank piercing on twist springback was analysed in-depth and discussed based on experimental and numerical results.

1. Introduction

With the development and use of high strength steels for structural parts, e.g. in the automotive industry, new challenges for precise prediction and control of springback in sheet metal forming processes have been highlighted by scientists and engineers. Generally, springback refers to the undesirable part shape change that occurs upon removal of constraints after forming. The shape deviation caused by springback always results in quality defects and difficulties during the assembly of components. For the past decades, a lot of work has been carried out to solve this problem. These approaches can be categorized into two types. The first type of approaches is to minimize springback by increasing the plastic deformation and hence reducing the difference of stresses along the sheet thickness. For example, Liu et al. [1] proposed to use variable blank holder force to keep springback at a minimum while avoiding cracking in the forming process. Li et al. [2] found that Springback decreased dramatically in samples held in the bent state for months. Tang et al. [3] proposed a metamodel-assisted optimization named as projection-based heuristic global search method (P-HGS) to minimize springback. The second type of approaches is to compensate for springback at die design stage, i.e. regardless of what the springback might be, the die is designed so that the final part shape after springback corresponds to the target part shape. For instance, Liao et al. [4] proposed a discrete curvature adjustment (DCA) strategy based on the plastic bending theory, in which springback calculation and reconstruction of the tool shape were based on curvature. For both types of approaches, it is vital to investigate the sensitivity of the blank shape design on springback prediction and control.

Recently, there has been growing interest in the twist springback of sheet metal products. Lee et al. [5] numerically studied the twist springback of the double S-rail stamping sheets based on isotropic–kinematic hardening laws and non-quadratic anisotropic yield functions. These authors investigated the influences of the blank holding force, lubrication and material direction on twist springback by means of numerical and experimental methods. Simplified one-dimensional plane strain analyses were also introduced to better understand the twist springback in forming processes. Li et al. [6] investigated the behaviour of twist springback in advanced high strength sheet components, where a twist rail was considered and the corresponding die and measurement tool were developed. Liao et al. [7] studied the twist springback of asymmetric thin-walled tube in rotary drawing bending process. Zhu et al. [8] investigated the effect of different constitutive models on springback prediction for rotary draw bending tube. In the case of U-shaped rails, for example, Takamura et al. [9] attempted to explain the mechanisms of twist springback by the following two factors: positive torque induced by the in-plane tensile and compressive deformation of the flange regions, and negative torque generated by the side wall opening and curl. Their results showed that the negative torque generated by the side wall opening, occurring in the die removal

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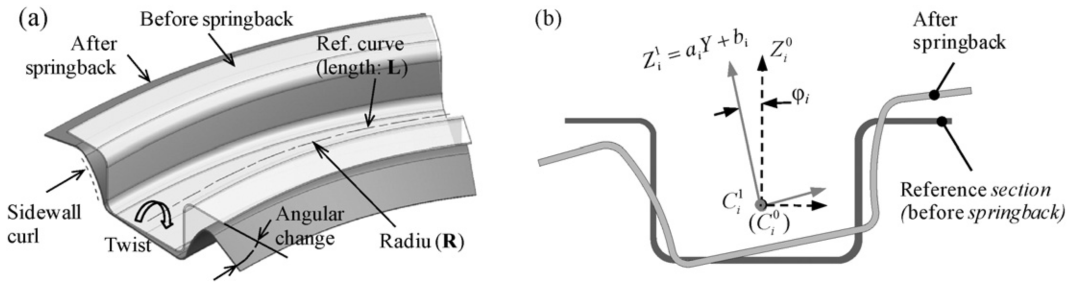

Fig. 1. (a) General types of springback (b) illustration of section twist springback with respect to the direction of central principal inertia axis.

process, was the dominant factor of the positive twist. A stroke returning deep drawing (SRDD) method was proposed to deal with the twist springback of a hat channel sheet by Geka et al. [10]. Their results showed that twist springback can be reduced by optimizing the conditions for two-step SRDD. Pham et al. [11] investigated the influence of the blank alignment relative to the tools on twisting magnitude. Their results showed that twist springback was caused by sliding (asymmetric flow of the side walls) of one of the two ends of the sample during the draw bending process. This sliding leads to an asymmetric springback of the different sections of the sample. These efforts provide insight into how twist springback can be controlled by the balance of material flow of the side walls and blank-holder walls. As a major factor affecting restraining force and material flow, the initial blank shape design may play a considerable effect on twist springback in deep drawing of sheet metal.

In the past decade, many studies have been conducted on blank shape determination in sheet metal forming by inverse finite element (FE) simulation in terms of individual case. Naceur et al. [12] presented a blank shape optimization approach that was based on the coupling between the inverse approach used for the forming simulation and an evolutionary algorithm. Their goal was to minimize the size of the blank shape and still ensure that the product was made without tearing the sheet metal. Padmanabhana et al. [13] investigated blank shape parameterisation using parametric NURBS curves and blank shape correction based on the control points displacement. De-Carvalho et al. [14] showed that the convergence of the latter method can be further improved by means of the sensitivity analysis, considering the influence of the mesh size and geometry definition. Chongthairungruang et al. [15] investigated the influences of blank pre-deformation on the springback of steel AHSS sheets under consideration of the elastic modulus change. Phanitwong and Thipprakmas [16] studied the springback factor depended on the ratio of die radius to thickness and bend angle. However, the inverse approach can only calculate the initial shape from the final shape without taking into account intermediate forming boundary conditions. But for complex parts obtained with non-linear strain path, the material nonlinearity and forming boundary conditions should be accounted for in the initial blank shape determination.

Blank shape is one of the most important parameters in the deep drawing process of advanced high strength steels, especially for complex industrial components. A reasonable initial blank shape design can reduce material and production costs, and also improve the uniformity of the strain distribution and the product quality. The present work aims at studying the influence of initial blank shape design on twist springback control in advanced high strength sheet steels. First, to explore the plastic deformation mechanism and develop a more effective numerical and experimental model for twist springback, a deep drawing benchmark of a non-axisymmetric curved channel rail was designed and conducted. A more reasonable definition of the twist springback with respect to the central principal inertia axes of the longitudinal cross-section of the rail was proposed. Second, a one-step formability analysis, which considers springback match and boundary constraint points, is presented to optimize the initial blank shape. Third, the interfacial friction coefficient between tools and blank was identified using the draw-in length of selected trace points in order to improve the accuracy of the numerical model. The optical 3D deformation measuring system ARGUS was applied to allow the validation of the numerical results (e.g. draw-in length of trace points) by direct comparison of the experimental and predicted deformation. Finally, the sensitivities of the constitutive model, material direction and blank piercing on twist springback was analysed and discussed in-depth.

2. Description of twist springback and its benchmark design

2.1. The evaluation of twist springback

The shape change after the forming process is driven by the release of the stored elastic energy during the tool removal. Compared to mild steel sheets, high strength steel sheets are more prone to this geometrical deviation because of the relatively high level of elastic deformation during the forming process. The previous research of springback has concentrated on 2D springback, i.e., angular change and sidewall curl,

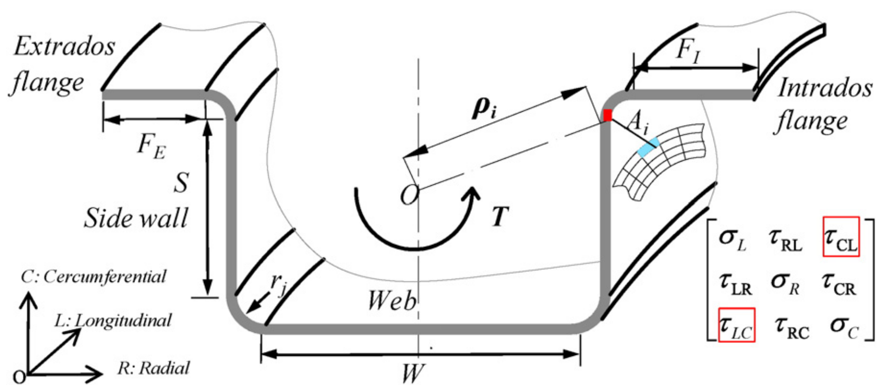

Fig. 2. Physical quantities used in the calculation of torsion moment.