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A improved polycrystal plasticity model and its deployment in stretch forming for highly formable sheet steels

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Abstract

Many flexible constitutive equations have been proposed in the last two decades for sheet forming simulations, but their use in forming industry is limited. The main reason is that various mechanical tests are required to determine the multiple parameters needed for such models. To solve this bottleneck, a polycrystal plasticity model, CTFP, has been proposed and validated using several forming steel grades. The CTFP model is improved by employing plastic anisotropy predicted from the Alamel model. Further the CTFP model has been deployed in stretch forming for a collection of highly formable sheet steels. The results demonstrate that the CTFP model can capture the yielding character among different coils, and can also detect the minor difference in stretching factor among different directions within same coil. The stretching factor derived from the CTFP model, as opposed to the work hardening and ductility, has dominant effect on failure for materials with similar mechanical properties. Failure occurs usually in the direction of minimum stretching factor.

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Keywords: constitutive material model, crystal plasticity, stretching, texture

1. Introduction

In the automotive industry finite element (FE) simulation has become a powerful technique for the modeling of sheet forming. It reduces the number of trials, which is often quite expensive and time-consuming, before a model goes into stamping production. FE simulations have also been used for optimization purposes during the design of sheet metal forming processes. The robust optimization technique has been developed recently to incorporate process

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variations and material scatters in the analysis. So the engineers can recognize and anticipate possible problems due to the influence of scatter in an early design stage [1].

There are different sources of scatter in forming processes, such as loading conditions, boundary and initial conditions, geometry and uncertainty in the numerical simulation in addition to material properties [2]. The scatter in material properties and thickness could have a remarkable effect on spring-back and failure behavior in stamping processes [3, 4]. Some research work has shown that the effect of material property can only be accurately modelled when the variations and correlations in the input parameters are represented with values close to the physically observed ones [5,6]. Even so, the Hill quadratic yield function [7] fitted with strain ratios is still widely used in industry, although this quadratic yield function cannot describe material anisotropy adequately [8,9]. The main reason that engineers are forced to use simple material models and work with a limited number of material scatter parameters for industrial applications is in general the lack of material data to calibrate the multiple parameters of flexible yield functions [10,11]. There are few non-quadratic yield functions with improved flexibility [12-14]. Recently a few more flexible yield functions have been presented with up to 18 fitting parameters or measured data points [15-17]. Clearly there is no lack of flexible yield functions, the bottleneck is how to generate relevant material data for fitting parameters.

For sheet metal forming industry, it is unrealistic to conduct many different mechanical tests to identify multiple parameters for large collection of coils. In addition, it is doubtful whether the variations in the yield loci among different coils can be measured accurately with mechanical tests. To avoid the time-consuming and costly mechanical tests while still providing enough and reliable input data to calibrate those flexible yield functions, an improved version of the yield locus description, the CTFP model, has been made and deployed in the study of stretch forming for coils of similar mechanical properties.

2. Materials and stretch forming

2.1. Materials and mechanical properties

To evaluate the accuracy of the CTFP model in forming operations, samples of 48 coils of highly formable sheet steel DX54D+Z were collected in this research. The DX54D+Z material, Ti-stabilized IF steel continuously annealed and hot dip galvanized with EDT surface texture, was chosen because of its wide application in automotive industry. The nominal thickness of the studied sheets was 0.8 mm, and measured thicknesses of the individual sheets were in the range of 0.75–0.83 mm. For the entire collection of materials, tensile tests in three directions were performed. Table 1 lists the average value and the standard deviation of mechanical properties and the plastic anisotropy *r*-value of the collected materials. The input for the polycrystal plasticity based CTFP model is the orientation distribution function, which was measured at half thickness of materials as described elsewhere [21]

Table. 1. The average value and standard deviation of the mechanical properties

Material	Coating	*t*, mm,	*Rp* [MPa]	*Rm* [MPa]	*Ag* [%]	*A80* [%]	*r*
DX54D+Z	GI	0.79 ± 0.02	171.9 ± 5.4	304 ± 5.7	24 ± 0.7	46 ± 2.5	1.95 ± 0.36

GI: galvanized, *t*: sheet thickness, *Rp*: yield stress, *Rm*: tensile strength, *Ag and A80*: uniform and total elongation, *r*: plastic anisotropy

2.2. Hemispherical punch stretching

Hemispherical punch stretching was conducted using an Erichsen universal sheet metal deep drawing machine. The punch has a diameter of 100 mm. The diameter of the die is 105 mm and the die shoulder radius is 8 mm. A blank holder force was set to 350kN to ensure complete clamping. The fully clamped circular blanks, 200 mm in diameter, were stretched at a punch velocity of 1.5 mm/s. The Erichsen machine stopped automatically when the punch force reached its maximum. Dry Teflon foil was used as a lubricant between the blank and punch. Necking or fracture occurred some distance away from the dome centre due to friction. During the stretch forming operation, deformation of the blank was measured on-line by using an Aramis 5M system. The system recorded images with a frequency of 15 Hz. The strains were calculated from digital image correlation using the speckle patterns applied on