

Drawbead Restraining Force Modeling with Anisotropic Hardening

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ABSTRACT

A detailed investigation of the influence of anisotropic hardening models on drawbead restraining force is presented in this paper. The recently modified Yoshida model is adopted to characterize the anisotropic hardening behavior for steels. A two-dimensional drawbead model is used and the restraining forces corresponding to several different bead penetrations are obtained and compared against experimental results. The comparison of the predicted results for the Modified Yoshida Model with isotropic hardening models indicates that the anisotropic hardening gives lower drawbead restraining forces in general. The impact of hardening models on springback is also presented, and it's demonstrated that the springback amount predicted by the modified Yoshida model is much closer to the experimental data than that predicted by conventional isotropic hardening model.

INTRODUCTION

Drawbead design is an integral part of stamping process development in die face engineering. Optimally designed layout and geometries of drawbead, such as the width, height and the radii, can provide effective restraining forces and therefore control materials flow for desired formability. The drawbead optimization process is mostly conducted through computer simulations thanks to the tremendous advances of stamping simulation technologies over the past decade [1,2,3]. The drawbead design process is usually divided into two consecutive steps. The objectives of the first step is to achieve the optimal layout and restraining forces of the drawbeads and that of the second step is to design the appropriate geometries of the drawbeads based on the restraining forces obtained in the previous step. Due to its

efficiency and simplicity, the line-beads or analytical bead is commonly used in draw-forming simulation. Modification of physical beads is a hard job and actually impractical in draw die development. Furthermore, the purpose of the drawbeads is to provide appropriate restraining forces to control the metal flow, and the line bead model is able to fulfill this purpose effectively. It is for this reason that analytical bead model was introduced in the early days of stamping simulation, and has been popular especially during early phase of forming feasibility study and process optimization. The appropriate physical bead geometries are then designed based on the required restraining forces and added to the die faces. Recent advancement in computational power enables the simulation of complete die face with physical beads to be done in a more practical manner than ever before. However, the use of real bead geometries is limited to the validation of the final draw design or for springback predictions in which bead geometries can play significant role [4].

It is therefore imperative to establish a corresponding relationship between particular physical bead geometry and the desired restraining force for a given material. The relationship could be expressed as a look-up table which allows stamping engineers to design correct drawbead geometry for the required restraining force. Such a relationship can be obtained through experiments or validated numerical simulations. Given the complexities of drawbead geometries and the wide range of materials used for stamping, however, it becomes clear that an exhaustive testing of all possible combinations would be prohibitively expensive and time consuming. A more advantageous approach would be to develop predictive simulation models aided by correlation with selectively conducted laboratory tests.

The restraining force generated by a drawbead is due to two mechanisms: the deformation force from bending of the metal as it flows through the drawbead, and the friction force from the rub of the sheet metal against the surfaces of the drawbead surfaces [5]. The classic linear Coulomb friction model has been the choice of majority of simulations for sheet metal forming due to its simplicity and the ease of implementation. The friction coefficient is assumed to be a constant value for any given pair of contact surfaces and the lubricant.

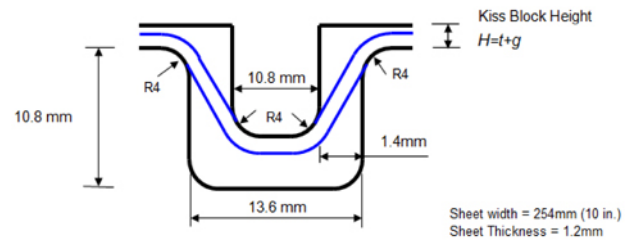


Figure 1. Drawbead geometry and setup

The accurate modeling of the bending deformation requires fundamental understanding and characterization of the elastoplastic behavior of sheet metals under large strain cycle loading. This includes the aspects of both the yield surface and its evolution during work hardening. Hill's anisotropic yield function is a good characterization for most of steels [6] and a series of non-quadratic yield models developed by Barlat and others provide better alternatives for aluminum sheet alloys [7,8]. Contrary to the yield surface, material hardening has commonly been assumed to be isotropic, though Bauschinger effect has long been observed. Recent studies found that anisotropic hardening model is critical to describe the mechanical behavior for the advanced material, such as high-strength steel [9,10,11].

This paper will present the recent studies of material hardening model on drawbead restraining force. A two-dimensional drawbead model is used, and both isotropic and anisotropic hardening models are used and the results are compared with each other.

DRAWBEAD MODEL

REVIEW OF EXPERIMENTAL SETUP

The experimental setup of the drawbead test and the tool geometry are illustrated in Figure 1, which was part of the Auto/Steel Partnership funded project "Enhanced Formability" [12, 13]. The bead cavity has a height of 10.8 mm, a width of 13.6 mm, and a radius of 4 mm for both entry and exit sides. The male bead is separated from the clamping binder for convenient adjustment of penetration. The clamping binder is to hold the sheet metal and its position is controlled by a kiss block. The height of the kiss block H is the total of the sheet metal thickness t and a pre-determined gap g , e.g. $H=t+g$. The male bead is 10.8 mm wide with 4 mm radii at the corners. The penetration depth of the bead can be precisely controlled to produce different restraining forces.

During the test, a long strip of sheet metal of 10 inches (254 mm) wide was first placed on top of the female bead and the binder was then clamped to the height of the kiss block. The male bead traveled down to a pre-determined penetration depth and remained stationary thereafter. The metal strip was then pulled through the drawbead. The drawbead restraining force read from the pulling force was recorded, along with the measurements of final metal thickness and major/minor strains.

Several steel grades were tested, including AKDQ, HSLA and DP600. The results for Cooled-Rolled HSLA350 with thickness of 1.2 mm are selected for this study. An extra gap of $g=0.318$ mm is used in the test for this steel grade.

SIMULATION MODEL SETUP

The simulation model to predict the drawbead restraining force (DBRF) is constructed using the commercial FEA code LS-DYNA®. Since the metal strip is 254 mm of width which is much larger than its thickness, it can be safely assumed that plane strain condition dominates the deformation. This assumption is also supported by the test data in which the measured strains in width are well below 1%. By considering the fact that 3D shell element is usually used in stamping simulations, one row of shell elements along the sheet strip are used and the nodes are constrained in the direction of width to model the plane-strain deformation. A fully integrated shell element formulation, e.g. type 16 in LS-DYNA, is employed with nine (9) integration points through thickness. This element type is widely accepted in both formability and springback predictions since it is able to more accurately capture the stress distribution in plane which is especially important in springback prediction. The FE model in a cross section view is illustrated in Figure 2. The bead height h is configured to match the eight cases in experimental setup as listed in Table 1.