Journal of Materials Processing Technology 187–188 (2007) 123–127

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Simulation-based prediction model of the draw-bead restraining force and its application to sheet metal forming process

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Abstract

Draw-bead is applied to control the material flow in a stamping process and improve the product quality by controlling the draw-bead restraining force (DBRF). Actual die design depends mostly on the trial-and-error method without calculating the optimum DBRF. Die design with the predicted value of DBRF can be utilized at the tryout stage effectively reducing the cost of the product development. For the prediction of DBRF, a simulation-based prediction model of the circular draw-bead is developed using the Box-Behnken design with selected shape parameters such as the bead height, the shoulder radius and the sheet thickness. The value of DBRF obtained from each design case by analysis is approximated by a second order regression equation. This equation can be utilized to the calculation of the restraining force and the determination of the draw-bead shape as a prediction model. For the evaluation of the prediction model, the optimum design of DBRF in sheet metal forming is carried out using response surface methodology. The suitable type of the draw-bead is suggested based on the optimum values of DBRF. The prediction model of the circular draw-bead proposes the design method of the draw-bead shape. The present procedure provides a guideline in the tool design stage for sheet metal forming to reduce the cost of the product development.

Keywords: Prediction model; Draw-bead restraining force; Box-Behnken design; Tool design

1. Introduction

Sheet metal forming processes have taken an important role in industries because of its various advantages. Product quality of sheet metal parts was effected by many process parameters such as the tool and die geometry, the draw-bead restraining force (DBRF), the blank shape, the friction and so on. The draw-bead has to provide the sufficient drawing force in order to control the material flow into the die cavity. DBRF directly depends on the shape of the draw-bead. The shape of the draw-bead, however, has been determined with expert engineer's experiences or trial-and-error procedures. A systematic tool design scheme incorporated with the accurate estimation of DBRF is necessary prior to the tryout stage of press working in order to reduce the development cost and time of a product efficiently.

The mechanism of DBRF and its application to forming simulation have been the subject of extensive studies in the past several decades [1–4]. Recent researches have been focused on the optimum die design incorporated with prediction of DBRF. Liu et al. [5] carried out the optimum design of the draw-bead in drawing tools of an auto-body cover panel with an improved hybrid optimization algorithm. An analytical model considering anisotropy is adopted to determine the draw-bead dimensions. Song et al. [6] carried out the optimum design of DBRF to minimize the amount of springback in a stamping process of a front side member of an auto-body.

In this paper, a simulation-based prediction model of DBRF is constructed with the Box-Behnken design and applied to the tool design for auto-body members. In order to construct the prediction model, shape parameters such as the bead height, the shoulder radius and the sheet thickness are selected as design variables and draw-bead analyses are carried out in each design case. The DBRF obtained from each design case by analysis are approximated with a second order regression equation. Then, the prediction model is applied to the shape design process of the draw-bead in an auto-body member by considering the formability of a product. The optimization of DBRF is carried out with response surface methodology in order to prevent wrinkling and

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0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2006.11.059

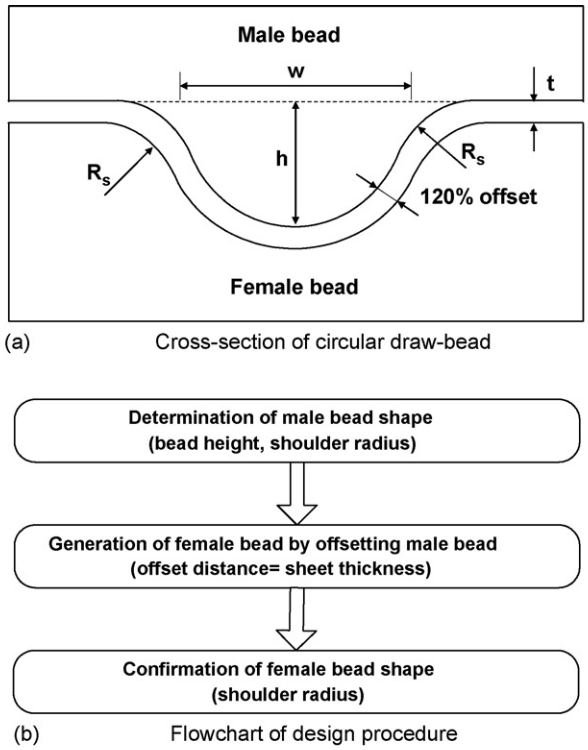

Fig. 1. Shape of the circular draw-bead and its design procedure.

tearing of a product. The converged optimum design is obtained with the iterative searching algorithm. The suitable type of the draw-bead is suggested based on the optimum values of DBRF. The prediction model of the circular draw-bead proposes the design method of the draw-bead shape.

2. Simulation-based prediction model of DBRF with the Box-Behnken design

DBRF, which is defined as the sum of bending and friction force, is the main parameter to control the formability of a product. Since the value of DBRF depends on shape parameters of the draw-bead, prediction of DBRF considering shape parameters can be utilized effectively at the initial stage of the tool design. In this paper, a new scheme is suggested to predict DBRF of the circular draw-bead with finite element analysis in the design space.

2.1. Circular draw-bead and design variables

The circular draw-bead is generally used in a stamping process of auto-body members since it is suitable to a large amount of the material flow. By reason of its general usage in sheet metal forming processes, the circular draw-bead is selected as an object to develop a prediction model of DBRF. Since DBRF is greatly influenced by the shape of the draw-bead, three design variables such as the bead height, the shoulder radius and the sheet thickness are selected to construct a prediction model. Fig. 1 explains the shape of the circular draw-bead and the design procedure.

Table 1
Range of design variables

Design parameter	Bead height (h)	Shoulder radius (R_s)	Sheet thickness (t)
Range (mm)	2–6	3–5	0.6–1.2

2.2. Box-Behnken design

The Box-Behnken design is utilized for a reliable approximation of DBRF. The value of DBRF obtained from the analysis is interpolated with a second order regression model. This design scheme has a precious advantage such that the design case constructed with the combination of the maximum or minimum values of the design variable can be avoided. Table 1 shows the range of design variables, which are determined from actual stamping processes. The factorial design technique with three levels is adopted for the selection of design cases.

2.3. Construction of a prediction model

Finite element analysis is carried out in each design case to construct a prediction model of DBRF. A commercial implicit finite element code, ABAQUS/Standard, is employed in the simulation. The material used for the blank is high strength steel of SAPH38. The material properties and the process variables are as follows: the hardening curve of $\bar{\sigma} = 765.8(0.0232 + \bar{\varepsilon})^{0.283}$ MPa; the Lankford values of 1.78; and the coefficient of Coulomb friction of 0.15. A blank is discretized with plane-strain elements and the die is modeled with the analytic rigid surface. The analysis is carried out with two-step simulations: bead formation; and drawing process as described in Fig. 2. The restraining force during drawing process increases to its ultimate value at the early stage and drops to a stationary value with the moderate drawing distance because the bending force and frictional force of the blank become in equilibrium with the external drawing force. In this case, the drawing distance is 40 mm and DBRF is measured with the averaged value of drawing forces in the steady-state region. Measured results in each design case are also illustrated in Table 2 and the prediction model of DBRF can be constructed as follow:

$$\begin{aligned}\text{DBRF(N/mm)} = & -26.93 + 24.87h - 15.98R_s + 159.09t \\ & - 3.14hR_s + 23.75ht - 29.89R_st - 2.95h^2 \\ & + 4.18R_s^2 + 85.95t^2 \end{aligned} \quad (1)$$

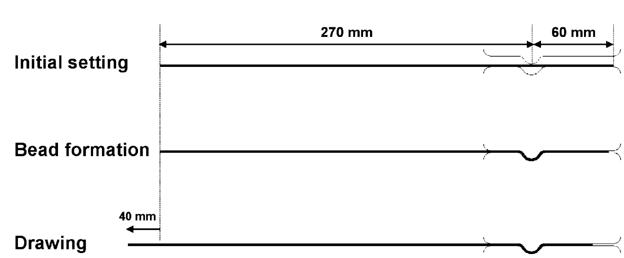

Fig. 2. Schematics of equivalent draw-bead analysis.