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A new strategy to optimize variable blank holder force towards improving the forming limits of aluminum sheet metal forming

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Abstract

The lower formability of aluminum alloy sheet greatly limits its application in reducing weight of stamping parts. This paper proposes a new strategy to optimize the variable blank holder force (BHF) and determine the drawing limit under the constant and variable BHF. The optimization strategy is based on the analysis of BHF formability window and integrated into FEM code to obtain time and spatial optimal BHF that applies on segmental binders. And then a stepped rectangular box of 60 mm drawing height with 10 segmental binders is adopted to validate the optimization strategy. The constant BHF experiment and the derived trajectory of optimal BHF are verified on a multipoint variable BHF hydraulic press and the experiment results correspond well with those of FEM optimization. This new BHF optimization strategy helps to determine time and spatial optimal BHF profiles simultaneity in a single round of FEM simulation, which makes it an effective method.

Keywords: Blank holder force; Forming limits; Sheet metal forming; Aluminum alloy sheet

1. Introduction

The requirement to reduce the weight of car components as a result of the introduction of legislation limiting emission has triggered the use of new lightweight materials, such as high strength steel sheet and aluminum alloy sheet. These materials could reduce the weight remarkably, but lead to more severe wrinkling or tearing than traditional low carbon steel because of their lower formability. Different advanced forming methods were used to increase the formability of aluminum alloy sheet, among which warm forming [1] and variable BHF (VBHF) forming [2] were two most effective ways.

About the application of blank holder force (BHF) towards improving the forming limits of sheet metal parts, Doege and Sommer [3] first examined the possibility of controlling the blank holder force with respect to the displacement of the punch as a means of safely avoiding the onset of either wrinkling or tearing, as is shown in Fig. 1. Hardt and Lee [4] established the first BHF system to maintain a constant blank holder displacement to allow a limited amount of flange wrinkling. In their second system, they introduced a generalized thickness variable to regulate the volume of material entering the die cavity, and the thickness variable was used to control the BHF. Later, Hardt et al. [5] employed a real-time closed-loop control of sheet forming operations to determine optimal blank holder force trajectories. Many other researchers conducted similar experiment based study in the area of VBHF, which were reviewed by Obermeyer and Majlessi [6].

As for the optimization strategy used for BHF optimization to increase formability of metal sheet, Cao and Boyce [7] estimated optimal binder force for a conical cup drawing by developing a PI controller. Krishnan and Cao [8] adopted the auto-regressive moving-average model (ARMA), which was inserted into the FEM commercial code to achieve optimal BHF for a non-circular part using segmental binders. An adaptive simulation strategy was developed by Sheng et al. [9] to adjust the magnitude of the BHF continuously during the simulation process. Chengzhi et al. [10] and Wang and Lee [11] presented a similar response surface methodology (RSM) to determinate the optimum BHF of various locations for a rectangular box. Though all these researchers gave effective approaches to optimizing the variable BHF, the issue of intersection in BHF formability window was not taken into account in their studies and no study was carried on optimizing BHF to determine maximal drawing limit. And vast number of time-consumed simulations

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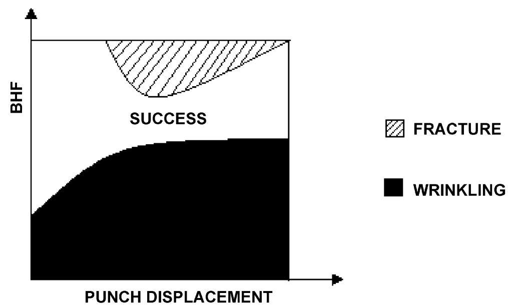

Fig. 1. BHF working window [1].

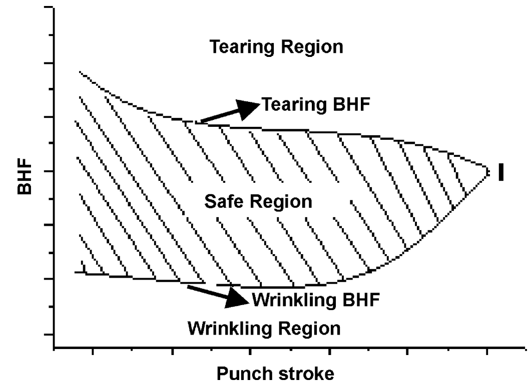

Fig. 2. The definition of BHF formability window.

required by RSM method to form response surface function restricts its practicality and thus only use in spatial VBHF optimization.

In this study, BHF formability window is first defined using the similar concept of Fig. 1. Then the intersection and three basic types of BHF formability window are discussed in depth, based on which the new BHF control strategy is developed. The new control strategy is then integrated into FEM code, through which not only the optimal VBHF that will not cause wrinkling and cracking will be obtained, but also the maximum drawing height under VBHF will be determined. A step rectangular box is selected to verify the strategy and the simulated result shows the drawing height and formability of aluminum alloy sheet are greatly increased under derived optimal BHF profiles comparing with those under constant BHF. The time and spatial BHF profiles are verified on a multi point VBHF press and the results correspond well with FEM simulation.

The rest of this paper is organized as follows: in Section 2, the BHF formability window will be first defined and analyzed, based on which the new control strategy will be developed. Section 3 will use FEM simulation integrating the BHF optimization strategy to conduct a closed-loop forming simulation for the step rectangular box. Optimal trajectories of the segmental are then gained and the maximum drawing height is also determined. The experiment verification will be conducted in Section 4 on a multipoint variable BHF hydraulic press, the results of which will be compared with those under constant BHFs. Section 5 states the conclusion.

2. PID control strategy for VBHF optimization

2.1. The definition and analysis of BHF formability window

The popular tool to denote the formability of sheet metal blanks in stamping is the forming limit diagram (FLD), through which the limits of formability in sheet metal operations are described in terms of the major and minor strains distributing in a grid coordinate system with the X- and Y-axes representing the minor and major strains. If there exist elements whose strains are in the failure zone of the coordinate system, this means the stamped part is cracked at the location where the elements are. Using the general concept of safe and failure zone in FLD, the BHF working window in Fig. 1 could be defined as a BHF formability window, which is shown in details in Fig. 2. The X- and Y-axis of BHF formability window coordinate system are referred as punch stroke and BHF force, respectively. The area under Wrinkling BHF is the wrinkling region, which means if BHF applying on tool at certain punch stroke is less than that of Wrinkling BHF, the part will engender wrinkling defect. While if the BHF is larger than the Tearing BHF at certain punch stroke, tearing will occur in the part, thus the area beyond Tearing BHF is denoted as tearing region. And the strip area between the Tearing BHF and the Wrinkling BHF is the safe region, which gives appropriate BHF range that will not cause wrinkling or tearing. No material could be drawn infinitely, i.e., every material has a formability limit, which means the part will undergo cracking at certain drawing height no matter VBHF is applied or not. Thus, unlike the BHF working window in Fig. 1, the BHF formability window in this study has a intersecting point, which is denoted by I in Fig. 2. This point of intersection demonstrates the forming limit, the maximum drawing height of this material.

With different combination of the Tearing BHF, Wrinkling BHF and intersecting point, the BHF formability window could have three basic types, which are shown in Fig. 3. In type (a), the part could be formed free of wrinkling and tearing under a constant BHF if the BHF is selected in the safe region of the BHF formability window, which of course could be achieved through careful experimental design. Moreover, the drawing limit of this material is bigger than needed drawing height of the designed part. And the constant BHF could be the BHF expressed in dash line in Fig. 3(a). However, inappropriate constant BHF will cause only single mode of failure, tearing or wrinkling before the drawing height is reached. In type (b), the drawing limit of this material is still bigger than needed drawing height of the designed part, but constant BHF will inevitably cross the region of tearing or wrinkling, so the part could not be formed successfully under constant BHF. And the part could only be formed under variable BHF. The drawing limit free of wrinkling and cracking under constant BHF is denoted by dash line in Fig. 3(b). While other constant BHFs will cause wrinkling and/or tearing before the needed drawing height is reached. In type (c), the drawing limit of this material is smaller than needed drawing height of the designed part. The maximum drawing height under constant or vari-