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Formation mechanism, prediction and control of the forming defects in transitional region during local loading forming of Ti-alloy rib-web component

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Abstract

Predicting and controlling the forming defects in transitional region are two key problems needed to be solved in the isothermal local loading forming of Ti-alloy rib-web component. To this end, the authors have conducted systematic works, which are reviewed here. First, according to the structural features of large-scale rib-web component, the finite element (FE) model of transitional region was established and validated by physical experiment. Then, the material flow and deformation inhomogeneity of transitional region are quantitatively studied by the FE model. In addition, the formation mechanisms of forming defects were revealed. Subsequently, an adaptive folding index was proposed to measure the severity of folding defect, based on which a quick prediction model of the folding defect was developed. Finally, the forming limit considering the forming defects in transitional region was determined by the stepwise searching method combined with the defect prediction model.

Keywords: Isothermal local loading forming; Rib-web component; Transitional region; Forming defects; Forming limit

1. Introduction

The isothermal local loading forming technology proposed by Yang et al. [1,2] is an innovative plastic forming technology. This forming technology combines the characteristics of local loading forming and isothermal forming,

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presenting the advantages in controlling the material flow, reducing the forming load, enlarging the size of component and enhancing the forming limit. It provides a feasible way to form the titanium alloy large-scale complex components with thin web and high rib (such as bulk-head) widely used in aircrafts and shows a good developing prospect [3,4]. These components mainly serve as the key load-bearing structures, thus increasing requirements in both of performance and shape are proposed in the forming process.

In the local loading forming, the component is formed by changing the partial loading regions in various loading steps. Thus, there exist the loading region, unloading region and transitional region in each loading step. The material in transitional region deforms under the constraints of loading region and unloading region, undergoing complex material flow and large uneven plastic deformation [5]. This may result in some forming defects such as folding defect, cavum defect and nonuniform microstructure, thus weakening the forming quality. Therefore, how to prevent the forming defects in transitional region is the critical concern during local loading forming.

By now, the studies on formation and prevention of forming defects are mainly focused on the integral forging. For example, by the combination of FE simulation and experiments, Zhang et al. [6] studied the formation mechanisms of underfilling and folding during forging of an aluminium-alloy ring seat. Chen et al. [7] revealed the formation mechanism of flow-through defect in the press forging of AZ31 magnesium-alloy sheets and determined the minimum sheet thickness that can avoid the flow-through defect. Petrov et al. [8] investigated the influence of die parameters and friction on the folding length in the forging of an aluminium part, and obtained the optimal die parameters and friction to prevent the folding defect. However, the forming characterises of local loading forming are greatly different from those in the integral forging.

To solve the challenges, the authors have done systematic investigations on the formation mechanism, prediction and control of the forming defects in transitional region during local loading forming. These works mainly include the FE modelling of transitional region, the material flow and deformation inhomogeneity in transitional region, and the formation mechanisms, prediction and control of forming defects. The present paper reports these developments which are of great significance to improve the forming quality of transitional region during local loading forming.

2. FE modelling of the transitional region

According to the structural features of large-scale rib-web component, the FE model of transitional region has been established using DEFORM-2D, as shown in Fig.1 [9]. Since the material flow perpendicular to die partition boundary is the main deformation, deformation in transitional region is simplified as a plane strain problem. The validity of this simplification has been verified by the authors in [9,13]. In the FE model, the top die is separated into two parts: Top die 1 and Top die 2. The typical local loading includes two loading steps. In the first step, a spacer block is implanted between the top die bed and Top die 1, which makes the billet under Top die 1 deform locally (Fig.1(a)). In the second step, the spacer block is removed with two top die parts being at the same level (Fig.1(b)). The structural features of transitional region model can be expressed by: a_{01}, a_{12}, a_{23}, a_{30}, b_1, b_2, b_3, billet height (H), and reduction amount (L). The thermal events are neglected. The material of billet is TA15 alloy, whose flow behavior is taken from the work of Shen [10]. The von Mises yielding criteria, shear friction model, local refined meshing and automatic remeshing are employed. The detailed modelling parameters can be found in [9,11].

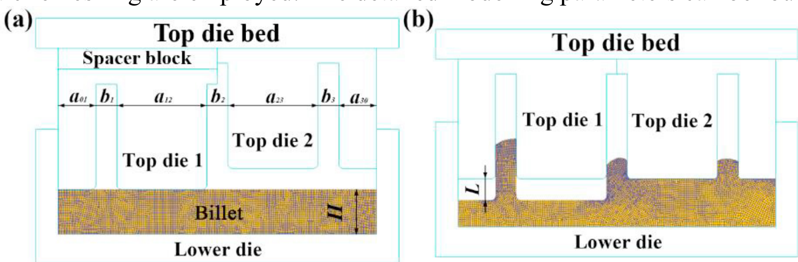

Fig.1 FE model of transitional region in local loading forming of rib-web component: (a) the first loading step; (b) the second loading step [9].

The FE model has been validated by physical experiment with the material of lead [9,11], as shown in Fig.2. It can be found that the flow lines, folding, shapes and feature sizes (rib heights, folding length, etc.) of the simulated