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Development of transition condition for region with variable-thickness in isothermal local loading process

Da-wei ZHANG[1,2], He YANG[2]

1. School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, China;
2. School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China

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Abstract: Using simple unequal-thickness billet combining isothermal local loading can control the metal flow and improve the cavity fill in manufacturing process of large-scale rib-web titanium alloy component with low cost and short cycle. The beveling transition pattern is well used for variable-thickness region of billet (VTRB) due to its simple and ample range of transition condition. The transition condition development in the local loading process has a significant influence on dynamic boundary of unrestricted portion of VTRB. With the help of reasonable assumptions, a mathematical model of transition condition development was established by theoretical analysis. The predicted results for local loading process of rib-web component using the established model were compared with the numerical and experimental ones, and the results indicated that the model of transition condition development is reasonable. Using the established model could deal with the dynamic boundary of unrestricted portion of VTRB well, and the model is suitable for the analysis of metal flow and cavity fill in local loading process of multi-ribs component.

Key words: rib-web component; isothermal local loading; unequal-thickness billet; variable-thickness region of billet; beveling transition pattern; titanium alloy

1 Introduction

Isothermal local loading method integrating the advantages of local loading and isothermal forging has been used to manufacture large-scale complex component made by hard-to-deform alloy such as titanium alloy and aluminum alloy [1−3]. The local loading method realized by dividing the upper or lower die into several parts is a simple and efficient way for large-scale rib-web component [3,4]. Using proper unequal-thickness billet (thickness of billet is changed using simple structure) combining local loading can control the metal flow and improve the cavity fill in manufacturing process of large-scale rib-web titanium alloy component with low cost and short cycle.

Common practice in the preform design is to consider planes of metal flow, i.e. selected cross sections of the component [5−7]. Thus, it is necessary to fast analyze metal flow and cavity fill on the cross section. For isothermal local loading process of large-scale rib-web component, the numerical simulation provides mass data and it is difficult to master basic forming law quickly, and then analysis and optimization for each metal-flow plane need numerous workloads. Conversely, the analytical model has a clear physical insight, and its computation is simple and efficient. The isothermal local loading process of large-scale complex-structure titanium alloy component is an isothermal forming process under elevated temperature and low loading speed. At these forming conditions, the assumption and simplification of slab method (SM) approach the true process conditions [8].

ZHANG and YANG [9] presented that the local loading states in local loading process of rib-web component were determined by geometric parameters of die (GPD) and geometric parameters of billet (GPB), respectively, and two loading processes of T-shaped component were designed which could reflect the local loading characteristic under different local loading states, as shown in Fig. 1. Using the SM, the analytical models have been established to describe the metal flow

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Corresponding author: He YANG; Tel/Fax: +86-29-88495632; E-mail: yanghe@nwpu.edu.cn
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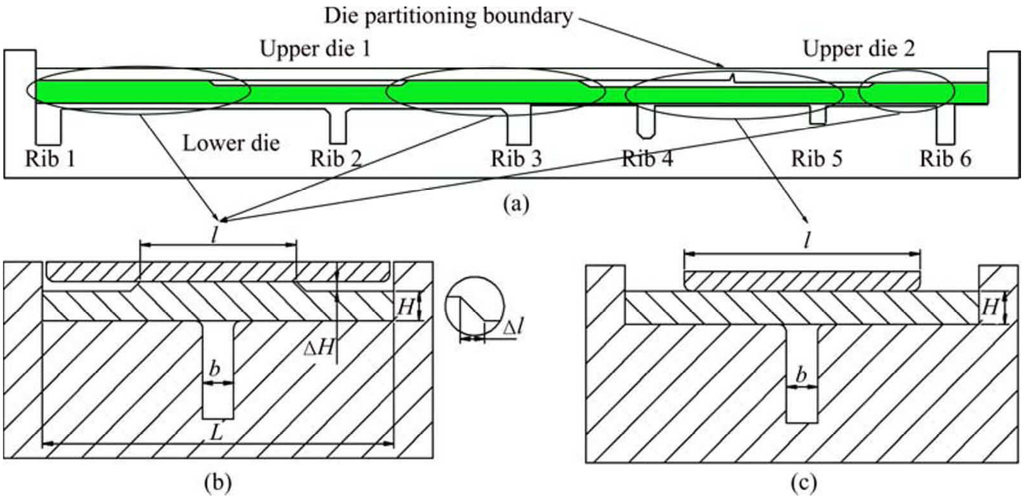

Fig. 1 Sketch of local loading processes of multi-ribs and T-shaped components: (a) Multi-rib component; (b) T-shaped component reflecting local loading state caused by GPB; (c) T-shaped component reflecting local loading state caused by GPD [9]

of the two T-shape components under local loading [9,10], and the metal flow on the plane can be fast analyzed by the model.

In local loading state caused by GPB, the constrained end of variable-thickness region of billet (VTRB) affected the development of geometric parameters in VTRB, and metal flow was determined by these geometric parameters, such as dynamic width of local loading, thickness of billet and transition condition of VTRB for certain material and component. The distance (L) between the center of rib cavity and the vertical wall of lower die was a parameter to describe the constrained end in Ref. [9], and the L was a constant in the SM model. However, in local loading process of multi-ribs component, the constrained boundary was dynamically changing. In order to solve the problem of dynamic constrained boundary, the process can be discretilzed into many intervals, and the SM model in the Ref. [9] was used in an interval, and then the position of constrained end and parameters L were updated in each interval. This needed to consecutively update the parameters in VTRB including the transition condition of VTRB. However, the development of transition condition was not considered in the previous study, where only the initial transition condition was considered. Thus, it urgently needs to explore the development of transition condition for VTRB in the local loading process.

The transition patterns used for VTRB should make the billet simple and be manufactured easily, and should have a flexibility adjustment. The beveling transition pattern met the above requirements due to its simple and ample range of transition condition. The beveling pattern was also adopted for the VTRB in the industrial process of a large-scale titanium alloy bulkhead [11]. Thus, only the beveling transition pattern was investigated in the present study. Based on analysis of deformation characteristic of VTRB, some reasonable assumptions about geometry development of VTRB were proposed, and then the model of transition condition development was established by theoretical analysis. The model was used to predict rib height combining with the previous SM model, and the predicted results showed a good agreement between the results obtained by experiment and finite element method (FEM). The established model was used to deal with the dynamic constrained end, and then metal flow and cavity fill in local loading process of multi-ribs component could be analyzed by analytical methods such as SM.

2 Transition condition and deformation characteristics in VTRB

The research on deformation behavior of VTRB indicates that [12]: the folding/lap is prone to be caused when the VTRB is set near rib cavity and die partitioning boundary, and setting VTRB at web position is a better choice to reduce or eliminate the possibility of folding. Thus, in order to simplify analysis, the forming process of T-shaped component shown in Fig. 1(b) is designed. The transition condition under beveling transition pattern is determined as follows:

$$R_b = \frac{\Delta l}{\Delta H} \tag{1}$$

where ΔH is the thickness difference of VTRB; Δl is the length of beveling.

Using physical modeling experiment combining slab method, ZHANG et al [10] found that the billet can be divided into several deformation zones according to metal flow, and the deformation zones in the forming process of T-shaped component are shown in Fig. 2(a).