Chinese Journal of Aeronautics, (2017), **xxx**(xx): xxx–xxx

CSAA

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

cja@buaa.edu.cn
www.sciencedirect.com

Unequal-thickness billet optimization in transitional region during isothermal local loading forming of Ti-alloy rib-web component using response surface method

Ke WEI, Mei ZHAN, Xiaoguang FAN *, He YANG, Pengfei GAO, Miao MENG

State Key Laboratory of Solidification Processing, School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China

Received 16 February 2017; revised 30 March 2017; accepted 5 April 2017

KEYWORDS

Die filling;
Folding defect;
Isothermal local loading forming;
Transitional region;
Unequal-thickness billet optimization

Abstract Avoiding the folding defect and improving the die filling capability in the transitional region are desired in isothermal local loading forming of a large-scale Ti-alloy rib-web component (LTRC). To achieve a high-precision LTRC, the folding evolution and die filling process in the transitional region were investigated by 3D finite element simulation and experiment using an equal-thickness billet (ETB). It is found that the initial volume distribution in the second-loading region can greatly affect the amount of material transferred into the first-loading region during the second-loading step, and thus lead to the folding defect. Besides, an improper initial volume distribution results in non-concurrent die filling in the cavities of ribs after the second-loading step, and then causes die underfilling. To this end, an unequal-thickness billet (UTB) was employed with the initial volume distribution optimized by the response surface method (RSM). For a certain eigen-structure, the critical value of the percentage of transferred material determined by the ETB was taken as a constraint condition for avoiding the folding defect in the UTB optimization process, and the die underfilling rate was considered as the optimization objective. Then, based on the RSM models of the percentage of transferred material and the die underfilling rate, non-folding parameter combinations and optimum die filling were achieved. Lastly, an optimized UTB was obtained and verified by the simulation and experiment.

1. Introduction

A large-scale component of titanium alloy with thin webs and high ribs that can meet the requirements of high performance and lightweight commonly serves as the key load-bearing

* Corresponding author.
E-mail address: fxg3200@nwpu.edu.cn (X. FAN).

Peer review under responsibility of Editorial Committee of CJA.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.cja.2017.07.005
1000-9361

structure in an aircraft. A typical large-scale Ti-alloy rib-web component (LTRC) is shown in Fig. 1, of which the length is greater than 1300 mm, and the width is approximately 1000 mm, but the largest rib width is only 18 mm. The manufacture of this component by a conventional method not only involves a tremendous forming load but also produces forming defects easily in terms of larger geometric size, complex structure, and difficult-to-deform property of titanium alloy. At this point, development of an alternative manufacturing technology is necessary for decreasing the forming load and achieving a defect-free LTRC. Isothermal forming can reduce the deformation resistance of a material as well as the forming load of a press. The local loading technique can reduce the required load and control the forming defects by reducing the loading area and controlling the material flow. By combining the advantages of both isothermal forming and local loading, an isothermal local loading forming (ILLF) method was proposed by Yang et al.[1–5] to form an LTRC. According to the local loading feature, the LTRC is divided into three loading regions, which are the first-loading region, the second-loading region, and the transitional region, respectively, as shown in Fig. 1. The forming process of local loading is implemented by alternation of loading dies, which will be discussed in Section 2.2.

The region near the die partition line is called the transitional region, which coordinates two alternated loading regions and takes a bridge effect between the first- and second-loading regions. Gao et al.[6] pointed out that a flowing material can transfer from a loading region into an unloading region during a forming process and twice transverse material flow with opposite directions occurs in the first- and second-loading steps sequentially. Furthermore, Gao et al.[7] concluded that the transferred material is the conclusive reason for the folding defect in the transitional region. Thus, how to decrease the transferred material in the transitional region is an urgent problem to be solved. Besides, since the material flow in the transitional region is rather complicated comparing with the whole loading forming, how to improve the die filling capability to reach a high-precision shape of the transitional region is another problem to be solved.

By now, extensive investigations focused on the transferred material and folding defect in the transitional region of ILLF have been carried out. Zhang and Yang[8] disclosed that the transferred material is determined by geometrical parameters of the transitional region. They also qualitatively described the material transferred from a loading region into an unloading region. However, they didn't provide an effective method for decreasing the transferred material. Gao et al.[5] revealed that using more loading passes to obtain a smaller reduction amount in each loading step is an effective method to avoid the folding defect. Nevertheless, Fan[9] presented that increasing loading passes would cause a workpiece to undergo a series of thermal cycles. In this case, the component would be in a high-temperature state for a long time, which may result in grain coarsening and prolonging the manufacture procedure. This is inconsistent with the needs for a high-performance component and a low-cost production. Therefore, increasing loading passes is not the priority selection to avoid the folding defect in the transitional region. Moreover, Sun et al.[10] revealed that the positioning of the partition line along a rib is preferable for the transferred material filling in the cavity of that rib prematurely, which is beneficial to the forming quality of the transitional region. Gao et al.[7] analyzed the effects of process parameters on the transferred material. It was concluded that decreasing the spacer block thickness and increasing friction could decrease the quantity of the transferred material. They[11] also revealed that increasing the fillet radii of left and middle ribs in the transitional region is conducive to suppress the folding defect. The aforementioned research provided some good guidance for improving the forming ability of the transitional region in ILLF. However, either folding or die filling problem was considered in these researches. In the whole forming process, folding and die filling were both investigated by Kim et al.[12], Wang et al.[13], Park and Hwang[14], respectively. It is indicated that folding and filling are two significant problems of common concern in the bulk forming process. On this basis, further research is required to consider both folding and filling in the transitional region of ILLF.

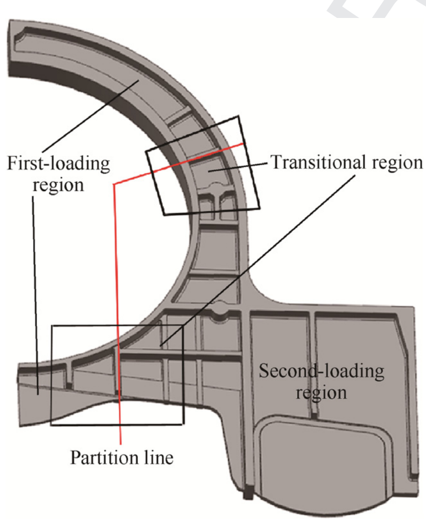

Fig. 1 A schematic diagram of a typical LTRC.

In decades, the finite element (FE) method integrated with an optimization design method for preforming billet has been extensively used for analyzing and controlling forming defects in the bulk forming process. By this means, the detailed locations of defects can be traced, and then subsequent modification or optimization of the billet can be made accordingly.

Torabi et al.[15] applied the Deform-3D FE software to simulate a blade forging process, in which the maximum filling ratio of the final die to the minimum flash volume, the forging force, and the strain variance of the final blade were considered as objectives of optimization, and then an optimized preforming billet with an extruded elliptical cross section was obtained by using the response surface method (RSM) and a multi-objective genetic algorithm. Yang et al.[16] also adopted the RSM to improve the deformation homogeneity of a typical aeroengine disk by optimizing the preforming billet based on FE simulation. Zhao et al.[17] presented backward simulations of a forging process which could directly provide a preforming billet from the final shape of forging. Lu et al.[18] combined FE simulation with a topological methodology to propose a criterion for element elimination and addition on the boundary of a preform shape. The objective of preform design is to achieve a desired preforming billet for sufficient filling of die cavity and flash minimization. Guan et al.[19] employed FE simulation and a quasi-equipotential field method to optimize a 3D preform shape in the hot forging of a pendulum mass, and the results showed that there were no underfilling and folding defect.

Please cite this article in press as: WEI K et al. Unequal-thickness billet optimization in transitional region during isothermal local loading forming of Ti-alloy rib-web component using response surface method, *Chin J Aeronaut* (2017), http://dx.doi.org/10.1016/j.cja.2017.07.005