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Prediction of tri-modal microstructure under complex thermomechanical processing history in isothermal local loading forming of titanium alloy

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Abstract: To control the tri-modal microstructure and performance, a prediction model of tri-modal microstructure in the isothermal local loading forming of titanium alloy was developed. The staged isothermal local loading experiment on TA15 alloy indicates that there exist four important microstructure evolution phenomena in the development of tri-modal microstructure, i.e., the generation of lamellar α, content variation of equiaxed α, spatial orientation change of lamellar α and globularization of lamellar α. Considering the laws of these microstructure phenomena, the microstructure model was established to correlate the parameters of tri-modal microstructure and processing conditions. Then, the developed microstructure model was integrated with finite element (FE) model to predict the tri-modal microstructure in the isothermal local loading forming. Its reliability and accuracy were verified by the microstructure observation at different locations of sample. Good agreements between the predicted and experimental results suggest that the developed microstructure model and its combination with FE model are effective in the prediction of tri-modal microstructure in the isothermal local loading forming of TA15 alloy.

Key words: titanium alloy; isothermal local loading forming; complex thermomechanical processing history; tri-modal microstructure modelling

1 Introduction

The large-scale complex components of titanium alloy have gained increasing applications in aviation and aerospace fields due to their features of high performance, light mass and high reliability [1]. However, it is difficult to form these components due to the hard-to-deform properties of titanium alloy and the complex shape of component. The isothermal local loading forming technology proposed by YANG et al [2] integrates the advantages of local loading forming and isothermal forming, providing a highly attractive way to form these components. For the forming of these components, the shape and the microstructure are highly required to assure the service performance. GAO et al [3] found that the tri-modal microstructure, consisting of equiaxed α (α_p), lamellar α (α_l) and β transformed matrix (β_t), can be obtained through near-β forging combined with conventional forging in the isothermal local loading forming of titanium alloy. The tri-modal microstructure is a preferable microstructure morphology due to its good combination of strength, ductility and fracture toughness [4]. However, the parameters of tri-modal microstructure, such as the content, scale and distribution of each constituent phase, still play a critical role in the final performance. Therefore, it is essential to study the prediction of tri-modal microstructure in the isothermal local loading forming of titanium alloy, so as to quantitatively control the microstructure parameters and mechanical properties.

During the local loading forming, only partial workpiece is loaded and the component is formed by accumulating local deformation, as illustrated in Fig. 1 [3,5]. The workpiece undergoes multi-fire forging with complex temperature routes and severe unequal deformation, which makes the development of tri-modal microstructure undergo complicated microstructure

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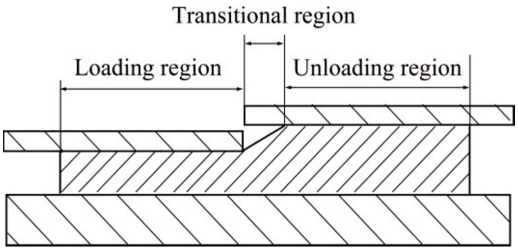

Fig. 1 Schematic diagram of local loading forming [3,5]

evolution phenomena. It involves the content variation of α_p, generation of α_l, spatial orientation change of α_l and globularization of α_l, and so on. Due to the complex microstructure evolution and coupling effects of multi-factors, it is difficult to predict the tri-modal microstructure in the isothermal local loading forming of titanium alloy.

By now, the existing microstructure prediction models for the isothermal local loading forming of titanium alloy are all aimed at the bi-modal microstructure which is produced at a simpler temperature route. LI et al [6] predicted the α_p grain size of bi-modal microstructure during the isothermal local loading forming of TA15 alloy by coupling an artificial neural networks (ANN) based microstructure model into the finite element (FE) model. FAN et al [7] established the through-process microstructure evolution model of bi-modal microstructure for the local loading forming of titanium alloy using internal state variable (ISV) method. It can predict the volume fraction and grain size of α_p. However, the production and evolution of α_l, an important constituent phase of the tri-modal microstructure, are not considered in the above models. GAO et al [8] and SUN et al [9] developed an ANN model to predict the content and grain size of α_p, and the content and thickness of α_l in the double heat treatments of TA15 alloy. However, they don't consider the spatial orientation change of α_l and globularization of α_l, which are important microstructure evolution phenomena for the development of tri-modal microstructure in isothermal local loading forming. Therefore, it is still needed to develop the prediction model of tri-modal microstructure under complex thermomechanical processing history in the isothermal local loading forming of titanium alloy.

In this work, the development mechanisms and rules of tri-modal microstructure in the isothermal local loading were revealed based on the staged experiments. A microstructure model was developed to correlate the parameters of tri-modal microstructure and deformation conditions. Then, the microstructure model was successfully implemented into FE model to achieve the prediction of tri-modal microstructure during isothermal local loading forming of TA15 alloy.

2 Experimental

TA15 titanium alloy used in this study has the following chemical compositions (mass fraction, %) of 6.06 Al, 2.08 Mo, 1.32 V, 1.86 Zr, 0.3 Fe, balance Ti. Its β-transus temperature is 1263 K. The initial microstructure is shown in Fig. 2, which consists of about 60% α_p and β_t.

An analogue experiment (Fig. 3 [10]) that can reflect the deformation characteristics of local loading forming was carried out in this work. It included two

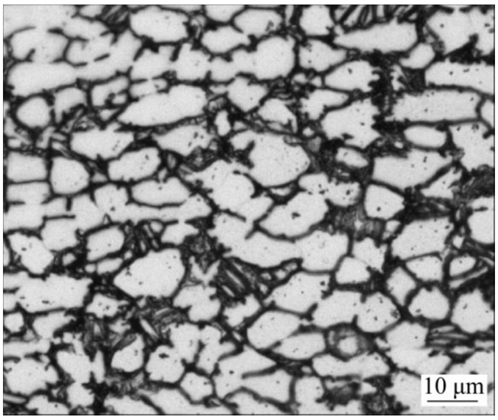

Fig. 2 Original microstructure of billet

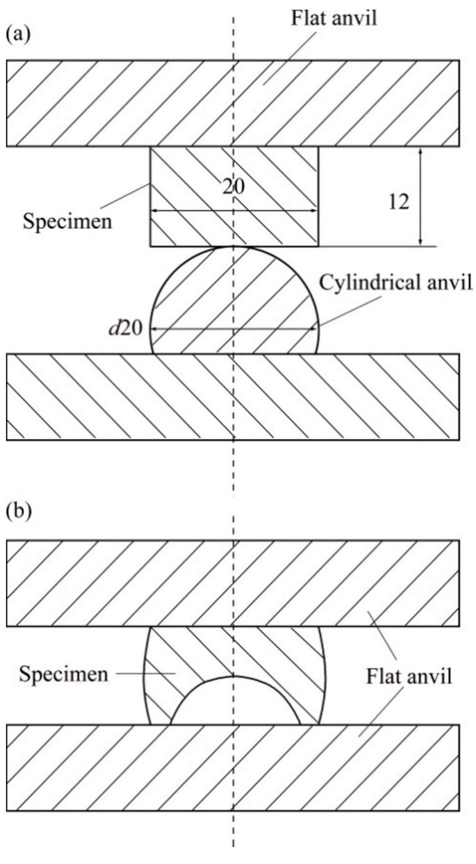

Fig. 3 Analogue experiment of local loading forming [10] (unit: mm): (a) First loading step; (b) Second loading step