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Dependence of microstructure morphology on processing in subtransus isothermal local loading forming of TA15 titanium alloy

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ABSTRACT

Control of microstructure morphology in isothermal local loading of titanium alloys is important to obtaining high performance components. To this end, the effect of thermo-mechanical processing on the microstructure development of TA15 alloy during isothermal local loading was experimentally investigated. It is found that bi-modal or equiaxed microstructure can be achieved when the heating temperature of the last loading step is not lower than that of the previous loading step. The volume fraction of primary alpha phase and the morphology of transformed beta matrix are determined by heating temperature and cooling rate in the last loading step, respectively. Tri-modal structure can be achieved by near-beta forging followed by conventional forging in the last loading pass. The volume fraction of each constituent phase in tri-modal structure is determined by the heating temperatures of the last two loading steps. The emergence of secondary alpha platelets in beta phase is promoted by increasing the heating temperature or cooling rate of the last loading step. Globularization of alpha lamellae can be avoided by thickening the alpha laths or decreasing the deformation degree in the last loading pass.

1. Introduction

The large-scale complex components of titanium alloys, with features of high performance, light weight and high reliability, are widely used in aviation and aerospace industries. It is difficult to form such component due to the high deformation resistance and low ductility of the material, and the complex shape and large projection area of the structure. The isothermal local loading forming (Fig. 1), which achieves integral forming by accumulated and segmented deformation, provides a feasible way to manufacture this kind of component [1–6].

Hot working of titanium alloys involves complex microstructure evolution. Diverse microstructure morphologies can be produced due to the dynamic and static microstructure developments as well as the allotropic phase transformation during hot working. Generally, four types of microstructure can be produced in hot working of two-phase titanium alloys according to the morphology of constituent phases: the lamellar structure, the equiaxed structure, the bi-modal structure and the tri-modal structure. Different microstructures exhibit different mechanical properties. For instances, the lamellar structure possesses good fracture toughness and creep properties but low strength and thermal stability; the equiaxed structure has good plasticity and fatigue property but low fracture toughness and high-temperature properties; the bi-modal structure shows better high-temperature strength and fracture toughness than equiaxed structure; the tri-modal structure exhibits enhanced fracture toughness and low-cycle fatigue property compared to bi-modal structure. For each type of microstructure, the microstructure features, such as volume fraction, size and aspect ratio of each constituent phase, also have significant influence on mechanical properties [7]. Thus, one important aim of hot working is to tailor the microstructure and mechanical properties of titanium alloy products. To this end, a lot of researches have been carried out on microstructure evolution during the thermo-mechanical processing of titanium alloys (e.g. [7–15]). It has been found that the microstructure morphology of titanium alloys is very sensitive to processing. So it is possible to control the microstructure morphology by choosing proper processing routes and parameters.

Isothermal local loading is a multi-stage hot working process involving severely uneven deformation. The large uneven deformation and diverse thermo-processing paths may result in varied microstructure morphologies. Fan et al. [1] reported that in near-beta local loading forming of large-scale rib-web component, four different morphologies can be produced under the effect of inhomogeneous deformation. Fan et al. [16] and Gao et al. [17] studied the microstructure evolution in the transitional region of local loading and suggested that the microstructure of transitional region is affected by the interaction of temperature, deformation degree and cooling rate. Sun et al. [2,18] found that the microstructure and mechanical properties vary for different

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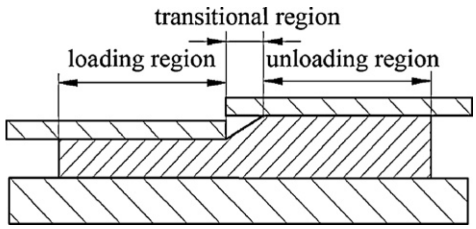

Fig. 1. Schematic diagram of local loading forming [2].

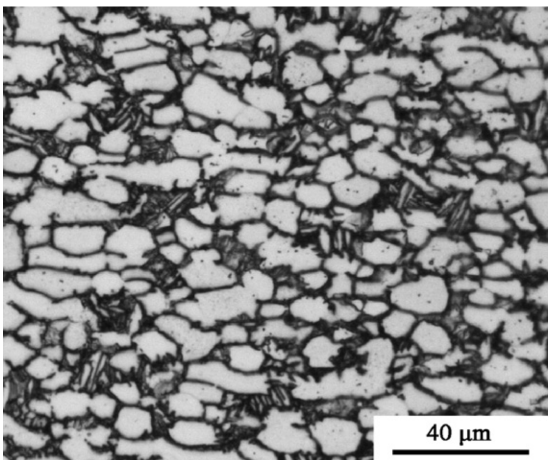

Fig. 2. Microstructure of the as-received TA15 alloy.

loading regions in both near-beta and conventional local loading forming.

To modulate mechanical properties of local loaded components, it is of significant importance to control the evolution of microstructure morphology in local loading forming. The objective of the present work is to propose methods for microstructure morphology control in local loading forming, so as to achieve desired combination of mechanical properties.

2. Materials and procedures

The material employed in the current study is a near-α TA15 titanium alloy with the chemical composition (wt.%) of 6.06 Al, 2.08 Mo, 1.32 V, 1.86 Zr, 0.30 Fe and balanced Ti, and measured β-transus temperature of 990 °C. The microstructure of the as-received material consisted of approximately 60% primary α phases within the transformed β matrix, as shown in Fig. 2.

In previous studies [16,17], an analog experiment was designed to simulate the deformation characteristics in isothermal local loading and it is also used in the present work, as shown in Fig. 3. In this experiment, the local loading was composed of at least one loading pass. Each loading pass consisted of two loading steps (i.e. the first-loading step and the second-loading step). In each loading

Table 1
Processing parameters.

Heating temperature (°C)	910–980
Total reduction rate (%)	50, 70
Strain rate (s^{-1})	0.01
Loading pass	1, 2
Cooling mode	AC, WQ

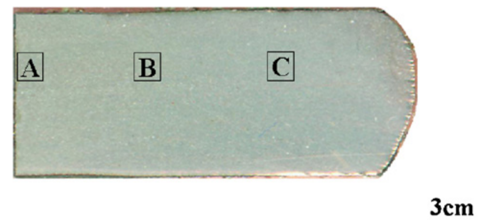

Fig. 4. Image locations for microstructure observation.

step, the workpiece was heated to the deformation temperature and partly deformed under isothermal conditions and then cooled down. After the local loading process, the specimen was annealed with the following heat treatment route: 810 °C/1 h/AC. The processing parameters are illustrated in Table 1. These parameters (e.g. heating temperature, deformation degree, cooling mode) can vary for different loading steps.

After the heat treatment, the specimen was quartered along the two symmetric planes and prepared for metallographic observation using standard technique. There exist the first-loading region, the second-loading region and the transitional region in the local loaded workpiece, which experience different deformation paths. The first-loading region undergoes large deformation in the first loading step but small passive deformation in the second-loading step. The second-loading region undergoes small passive deformation in the first-loading step and large deformation in the second-loading step. The transitional region, however, deforms directly and indirectly in both loading steps. To capture this phenomenon, microstructure observation was carried out on typical locations of the workpiece, as marked by zones A–C in Fig. 4. Finite element analysis suggested that zones A–C could reflect the deformation characteristics in the first-loading region, transitional region and the second-loading region.

3. Results and discussion

Equiaxed and bi-modal structures are two common microstructure morphologies for two-phase titanium alloys. Both are composed of equiaxed primary alpha phase and transformed beta matrix, though the bi-modal structure possesses a relatively small fraction of equiaxed primary alpha. The equiaxed or bi-modal structure can be obtained by fixing the deformation temperature in the whole local loading process, as shown in Fig. 5. Fig. 5(a)–(c) shows the microstructures of different loading regions by 1 pass local

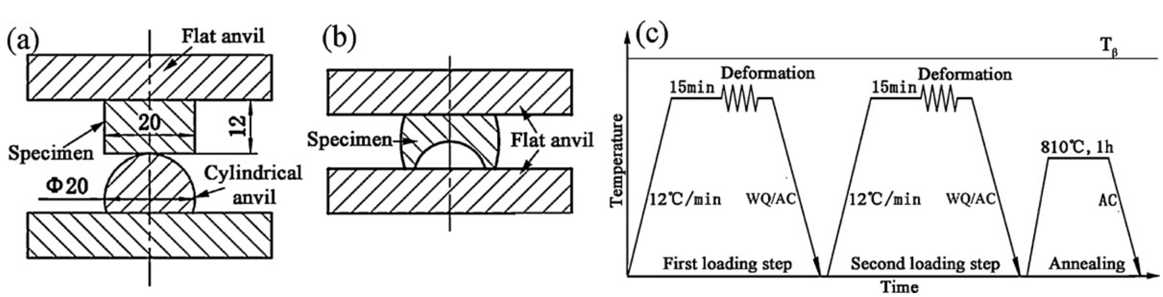

Fig. 3. Analogue experiment for local loading forming (one pass, two steps): (a) the first loading step; (b) the second loading step and (c) the processing route.