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Modeling the anisotropy of hot plastic deformation of two-phase titanium alloys with a colony microstructure

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ABSTRACT

Two-phase titanium alloys deform heterogeneously in primary hot working due to the strong anisotropy of plastic deformation of colony structure associated with the transformation crystal structure, morphology and orientation relationship between the constituent phases. To understand the heterogeneous deformation in primary hot working, a homogenized crystal plasticity constitutive model is developed for a single colony which relates anisotropic deformation behavior to microstructural features. Efforts are made to model the morphological effects which cause the abnormally low measured critical resolved shear stress (CRSS) of two basal < a > slip systems and the anisotropic Hall-Petch strengthening associated with the Burgers orientation relationship. The model is able to capture the deformation characteristics and texture evolution in compression of colony structure. It is found that the morphological effects cause the formation of transverse texture and continuous flow softening in hot compression.

1. Introduction

Titanium alloys have been gaining increasing applications in many industrial domains due to the high specific strength and excellent corrosion resistance (Leyens and Peters, 2003; Lütjering and Williams, 2007). Primary hot working is necessary to transform colony structure to equiaxed structure such that ductility and fatigue resistance of the titanium alloy can be greatly enhanced. Thus, it is crucial to tailoring the mechanical properties of titanium alloy components.

Titanium alloys are well known to deform heterogeneously due to the strong anisotropy of plastic deformation of hexagonal close-packed (hcp) α phase (Bieler and Semiatin., 2002). Moreover, the deformation heterogeneity can also be complicated by the microstructural morphology (Zhang and Dunne, 2017). The α colony contains a large number of parallel α laths which hold a specific crystal orientation relationship with β matrix (Fig. 1(a)). This special alignment of α phase intensifies the heterogeneous deformation from colony to colony. The heterogeneous deformation results in heterogeneous microstructural development and complicates primary hot working. Experimental work by Bieler and Semiatin (2002) suggested that breakdown (globularization) of α lamellae is inversely related to the calculated Taylor factor which is determined by the crystal orientation of α phase and applied stress state. Globularization is more efficient when both prism and basal slip systems are activated. Roy and Suwas (2017) found that slip activation, formation of intra-α grain boundaries and evolution of interfacial energy are orientation sensitive during deformation of the colony structure, which makes the static globularization in annealing also orientation dependent.

Crystal plasticity (CP) models are effective tools for understanding the heterogeneous deformation from the intrinsic crystalline anisotropy. Extensive modeling and simulation work has been carried out on titanium alloys for the prediction of mechanical

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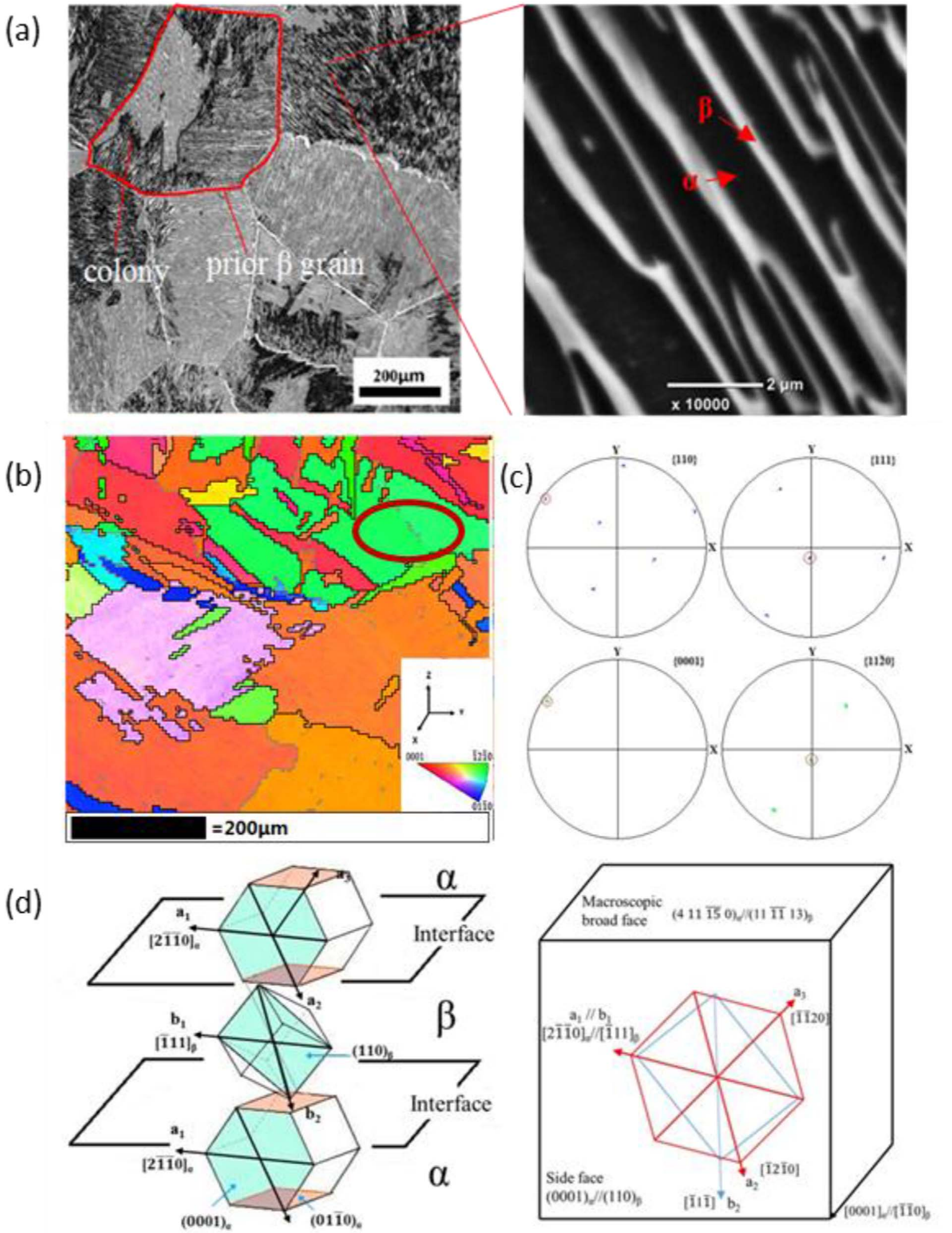

Fig. 1. Typical colony structure of a two-phase titanium alloy obtained by furnace cooling from β phase field: (a) microstructure hierarchy; (b) IPF colour map of the α phase; (c) pole figures of the constituent phases in the colony indicated by the red circle in Fig. 1(b); (d) crystal and interface orientations between the α and β phases. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)