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On recrystallization of the α and β phases in titanium alloys

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ABSTRACT

Recrystallization during hot compression of the Ti5553 alloy in the two-phase α+β regime has been studied with the help of fine scale, orientation image mapping techniques. We find two distinct recrystallization processes. The first is associated with the well-known α globularisation process, and results in the loss of the Burgers orientation relationship between α and β, with the consequent randomization of the of the sharp, starting transformation texture. An alternative, dynamic recrystallization process is also observed in which newly recrystallized α and β grains form with the Burgers orientation relationship with each other. We call this epitaxial recrystallization.

1. Introduction

Thermomechanical processing of titanium alloys involves processing in the high temperature β (bcc) single phase field and the lower temperature α+β (hcp + bcc) phase field to control microstructure, texture and properties [1]. α characteristically precipitates from β as laths with the Burgers orientation relationship (BOR): $(110)_\beta \,||\, (0001)_\alpha$ and $[1\bar{1}1]_\beta || [11\bar{2}0]_\alpha$. One of the objectives of thermomechanical processing within the α+β phase field is to convert lath α to a globular or spheroidal form through the stored work of deformation. The globularisation (or the synonymously used term 'spheroidisation') process is attributed to α lath pinch-off by an α boundary grooving process driven by subgrain formation in the α and β phases during hot deformation, or the fragmentation of α by shear due to planar slip [2–5]. The process may be completed by static spheroidisation on subsequent annealing in the two-phase field. The interplay between β recovery and recrystallization and α globularisation determines the microtexture of thermomechanically processed samples, as well as the breakdown of the BOR between the two phases and the nature of the α/β interface. Curiously, conventional dynamic recrystallization [6] of α in such two phase structures, as distinct from the globularisation process, has received little or no attention in the literature.

An understanding of the recrystallization processes that drive structure and microtexture evolution in titanium alloys is important because the mechanical behavior of titanium alloys is critically dependent on the crystallography, morphology, size and distribution of the α phase in the β matrix [1]. These alloys constitute examples of relatively coarse two-phase structures in which both phases plastically deform. The importance of local texture is accentuated by the plastic anisotropy of the α phase.

In this paper we (a) report observations that clearly distinguish between globularisation and conventional dynamic recrystallization of α, enabled by high resolution, orientation image mapping (OIM) by precession electron diffraction (PED), subsequently referred to as PED-OIM (b) describe the microtexture and misorientations between α and β phases that evolve as a result of these distinct processes, (c) provide evidence for an unusual 'epitaxial' recrystallization of α and β in an interdependent manner during dynamic recrystallization, (d) provide evidence for the special β/β grain boundary misorientations that arise out of these processes and finally (e) address the implication of these results for the nucleation of recrystallization.

These results have been enabled by the characterization of texture and structure evolution during hot compression in a Ti5553 alloy with large β grain size and a starting lamellar α structure. The large β grain size has enabled us to determine recovery and recrystallization processes occurring within a single β grain, and in some instances track the same β grain before and after heat treatment. The β-stabilized alloy allows the retention of the hot processed structure of the β phase by rapid cooling after hot compression.

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2. Experimental

A metastable β Ti-5Al-5Mo-5V-3Cr otherwise known as Ti5553, provided in the non-consumable, vacuum arc melted condition was used for this study. The β grain size of this as-cast material is large and ranges from 2 to 5 mm. The distribution of the α phase within these grains, obtained by annealing at 765 °C to a volume fraction of about 30%, is shown in Fig. 1a. Fig. 1b and c show that the α phase is present in all 12 variants of the Burgers orientation relationship. However a specific grouping of these variants is often observed as triangular trivariant clusters with a common $[11\bar{2}\,0]_\alpha$ axis (Fig. 1c) as characterized in detail earlier [7]. We report here the characterization of material after hot compression at 765 °C [8]. The analysis in this paper is largely from samples compressed to 0.5 strain at a strain rate of 10^{-3} s^{-1} (with the exception of some samples deformed at 10^{-1} s^{-1} and 10 s^{-1}). At this strain rate and temperature, there is no significant volume change of the α phase on deformation since there was no measureable adiabatic heating.

The tests were conducted on cylindrical specimens of 15 mm length and 10 mm diameter using a 100 KN servo hydraulic test frame manufactured by DARTEC, Stourbridge, UK. The samples were further annealed at 765 °C in the α+β phase field for 1 hour at the same temperature as the deformation temperature, in order to enhance static recrystallization of both phases without change in volume fraction of the phases during the anneal from that present at the deformation temperature. Samples were also heat treated above the β transus at 900°C for 30 minutes to realize β recrystallized structures. The deformed samples were cut parallel to the compression direction. Foils were prepared from approximately the middle of the sample, and characterized using a 200 kV FEI Tecnai G2 T20 S-Twin Transmission Electron Microscope with a Precession Electron Diffraction (PED) control unit, Digistar, supplied by Nanomegas. Supporting software such as ASTAR (Nanomegas) and TSL OIM (EDAX) were used for post processing of the OIM data. In the Nanomegas system, the sample area in a thin foil is scanned by a focused electron beam with a probe size that can be controlled by the settings of the microscope, while being simultaneously precessed by a small angle about the optic axis. An externally mounted fast CCD camera records the electron diffraction patterns generated during the scan, and these are compared to a template of simulated

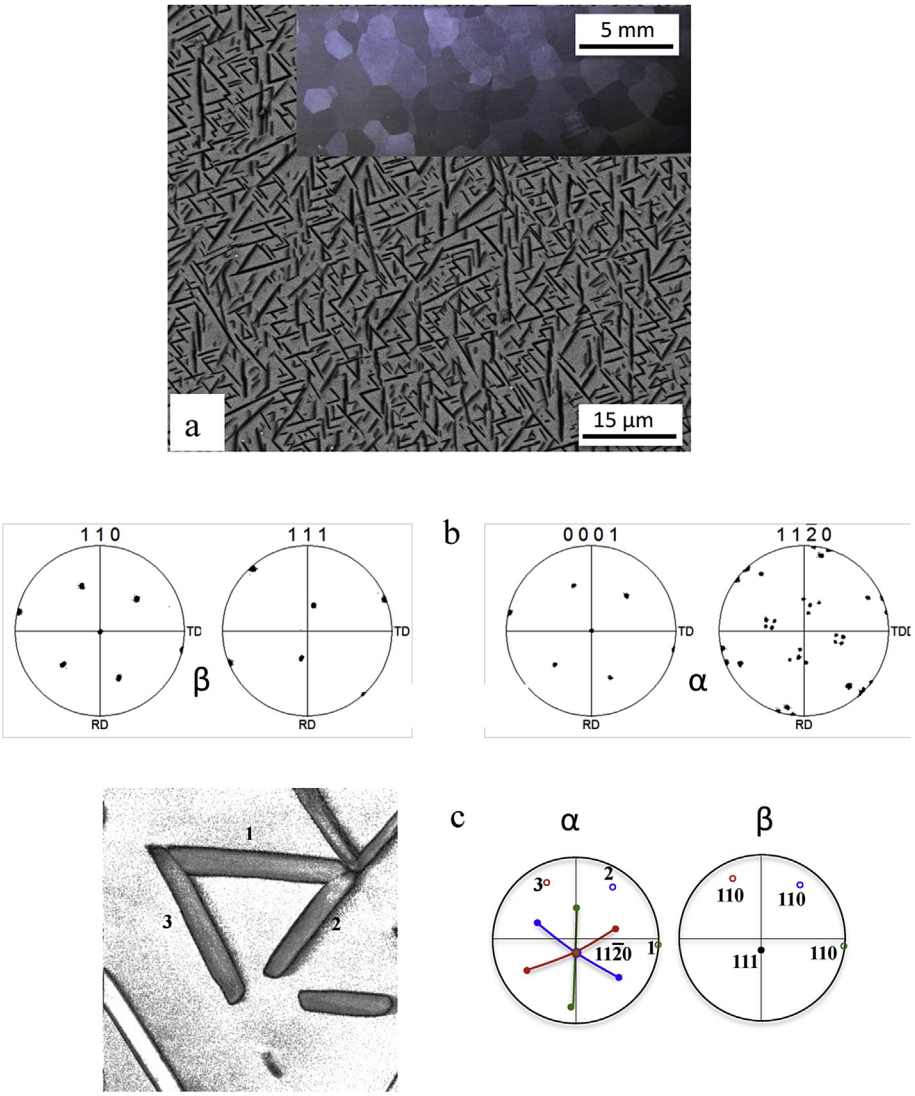

Fig. 1. (a) The starting microstructure before deformation showing α plates within a single β grain. The inset shows the β grain size. (b) The pole figures are from an EBSD scan of an area such as in (a) and shows that all 12 variants of the α phase exist in the Burgers orientation relationship [7] (c) a TEM image of typical triangular arrangements of α plates. The pole figures from PED-OIM show that these share a common $[11\bar{2}0]_\alpha$ direction parallel to $[111]_\beta$. The open circles are 0001 poles of the α phase that are each parallel to an equivalent 110 pole.