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Effect of boron addition on formation of a fine-grained microstructure in commercially pure titanium processed by hot compression

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This paper is devoted to comparative investigation of recrystallization behavior during uniaxial hot compression at 600–900 °C of cast commercially pure titanium (CP-Ti) modified with boron and free of boron as well as of CP-Ti in initial wrought condition. Using optical microscopy and EBSD analysis it has been revealed that the boron addition in an amount of 0.2 wt% promoted much more uniform strain development and intensive dynamic recrystallization during hot compression in cast CP-Ti modified with boron as compared with cast CP-Ti free of boron. At the same time, hot compression led to similar fine-grained microstructures in cast CP-Ti modified with boron and wrought CP-Ti. The obtained results suggest that the boron additions to CP-Ti may reduce postcast processing steps and thus reduce the overall cost of produced fine-grained materials out of CP-Ti by means of hot working.

1. Introduction

Titanium alloys are widely used as structural materials in aircraft, space and medical engineering because of their high specific strength and excellent corrosion resistance [1,2]. One of the key problems associated with titanium alloys is a coarse-grained structure (with $d \sim 1$ to 10 mm), which is typically formed during freezing and cooling in as-cast ingot materials. As-cast ingots of titanium alloys are usually subjected to primary hot working to breakdown the cast structure and produce semi-finished materials like rods, slabs, plates, which might be applicable for either practical use or secondary wrought processing aimed at obtaining fine- or ultrafine-grained microstructure and enhanced mechanical properties. As is known [1], standard primary hot working of as-cast titanium alloys increases the material cost (as compared with as-cast ingot) in about two times. The grain size typically obtained after primary hot working is usually varied in the range of $d = 15–50$ μm [3–9]. The grain size refinement reached due to primary hot working improves the material workability that enables subsequent secondary wrought processing at lower temperatures (below the β-transus temperature). Hot, warm or cold (down to cryogenic temperatures) forging, forging followed by rolling, equal channel angular extrusion, hydrostatic extrusion etc. have been recently used to fabricate fine- or ultrafine-grained materials out of titanium alloys [3–11]. No doubt that this leads to a significant additional cost increase of the produced fine-grained materials.

To reduce a number of wrought processing steps it makes sense to modify titanium alloys with boron in an amount of ~0.1 wt%. It is known that minor additions of boron in titanium alloys lead to formation of TiB whiskers, which refine the as-cast structure, weaken the casting texture, improve the hot workability and increase strain homogeneity during hot working [12–19]. However the effect of minor additions of boron on strain homogeneity and formation of fine-grained microstructure during hot working of CP-Ti has not been studied yet.

The present work was aimed to investigate the effect of the boron addition on recrystallization behavior of CP-Ti subjected to hot compression. Recrystallization behavior of CP-Ti modified with boron with initial as-cast structure is compared with that of CP-Ti free of boron with initial as-cast and wrought structures.

2. Materials and experimental

CP-Ti (Grade 2) in as-cast and wrought (hot-rolled) conditions as well as CP-Ti modified with 0.2 wt%B (further designated as Ti–0.2B) in as-cast condition were taken as initial materials. The cast conditions were prepared as 100-g ingots in a laboratory arc-melting furnace under argon atmosphere. As-cast CP-Ti was obtained by remelting of the wrought CP-Ti. As-cast Ti–0.2B was obtained by remelting of the wrought CP-Ti and boron powder.

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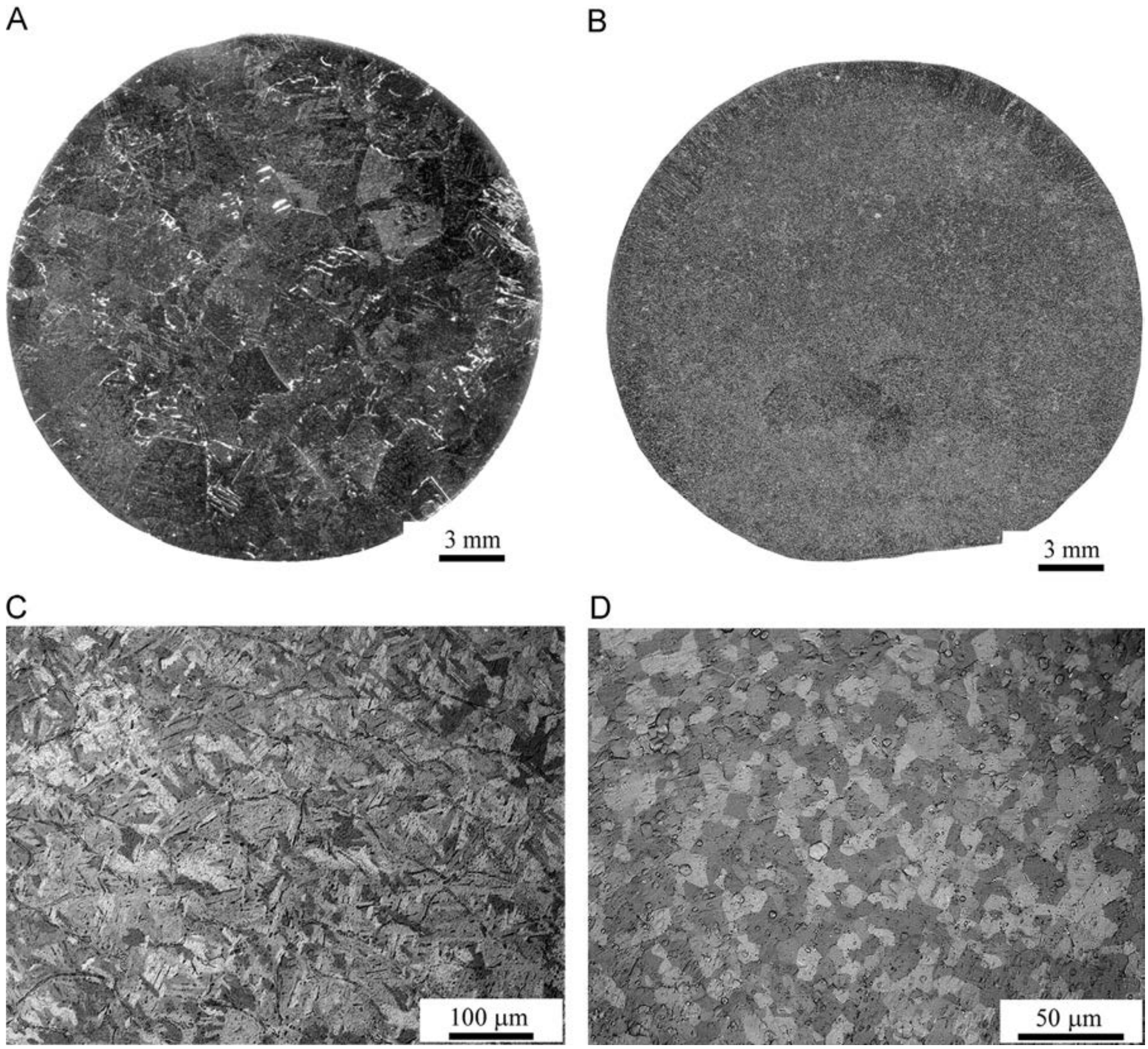

Fig. 1. Initial (a, b) macrostructures and (c, d) optical images of (a) cast CP-Ti, (b,c) cast Ti–0.2B and (d) wrought CP-Ti; (c) black fibers are the borides.

The boron powder with purity 99.5% was supplied from the Russian enterprise OAO Aviabor. To have appropriate homogeneity, the ingots were remelted at least 7 times. The as-cast materials were annealed in the single β-phase field (at $T=950$ °C (1 h)) followed by furnace cooling to simulate cooling conditions of a large-scale ingot.

The β-transus temperature of the obtained materials was evaluated using a differential scanning calorimeter DSC STA 449 F1 Jupiter. To do it, 50 mg samples were heated at a rate of 20 K/min from room temperature to $T=1200$ °C and cooled under dynamic argon atmosphere.

As-cast and annealed in the β-phase field alloy conditions were subjected to compression tests. The compression specimens with dimensions of $5\times5\times8$ mm^3 were prepared by electrospark cutting followed by fine grinding of surfaces. The compression tests were made at $T=20$ and 600–900 °C with an initial strain rate of $\varepsilon'=10^{-3}$ s^{-1} to an engineering strain of $\varepsilon=60\%$ at elevated temperatures and to fracture at room temperature. The compressed specimens were removed out of the furnace zone during less than 30 s. Two specimens were tested at each temperature. The true stress–strain curves were drawn taking into account a uniform increase in the cross section of specimens during compression. A Schenck Trebel RMS-100 machine was used for mechanical testing.

For microstructural observations, the compressed specimens were cut parallel to their compression axes along their diameter and the cross section was studied. Microstructural examination was carried out using optical (Olympus GX-51) and scanning electron microscopy (Mira-3 Tescan). For EBSD analysis a scan-step size was varied from 0.2 μm (for the specimen strained at $T=600$ °C) to 1 μm (for the specimens strained at $T=700$–900 °C). Taking into account the accuracy of misorientation determination, the boundaries with a misorientation angle less than 2° were excluded from consideration. The grain boundaries were assumed as high-angle ones if their misorientation angle was more than 15°. EBSD analysis was also used to evaluate the mean size of recrystallized grains and to obtain inverse pole figures.

3. Results and discussion

3.1. Initial as-cast materials

Fig. 1a,b represents the macrostructures of as-cast ingots of CP-Ti and Ti–0.2B. Coarse prior β grains with a size $d\sim1$ mm were distinguished in CP-Ti, whereas the structure was much finer in Ti–0.2B. The boron addition led to formation of uniformly distributed TiB whiskers with a length up to 100 μm located predominantly along prior β grain and α colony boundaries (Fig. 1c). The mean sizes of prior β grains and α colonies in cast Ti–0.2B was