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The influence of Sc on α/β transformation of Ti

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Abstract

Samples of pure Ti, Ti–2Sc, Ti–5Sc, Ti–25Sc and Ti–37Sc (wt%) were prepared by vacuum arc melting technique and examined by optical microscope (OM), X-ray diffraction (XRD), differential thermal analyzer (DTA), and hardness test. The results showed that the introduction of small amount of Sc helps refining as-cast microstructure and increases Vickers hardness from 190 $HV_{0.01}$ (pure Ti) to 308 $HV_{0.01}$ (Ti–2Sc). A lamellar microstructure of α was obtained in as-cast alloy. The grain size of β phase was larger than 100 μm and α lamellar nucleated at β grain boundary. The lattice constants of as-cast Ti–Sc alloys were measured by XRD method. Microstructure evolution of Ti–Sc binary alloys annealed at different temperatures was revealed by OM too. Furthermore, as β-phase stabilizer, the function of Sc was thermodynamically analyzed.

Keywords: Ti–Sc binary alloys; Microstructure evolution; Phase transformation; Thermodynamics

1. Introduction

As important structural materials, titanium-based alloys have attracted much attention and remained long time hot topic since 1950s. However, there are still several issues associating with structural applications of Ti alloys: their low room temperature plasticity, poor high temperature strength, and low service temperature. One way to solve or mitigate those problems is to develop new alloying systems of better properties.

A number of studies have been devoted to the influence of Al, Si and transition elements on microstructure and mechanical properties of Ti and Ti–Al alloys [1–8]. Influence of rare earth elements on microstructure and mechanical properties of Ti alloys has been investigated extensively recently. The addition of Ce, Dy, Er, Gd, La, Nd, Y, etc. had positive effect on mechanical properties of Ti alloys [9–14] with Ce, La and Nd increasing and Er decreasing while Dy, Gd and Y having little influence on α/β transformation temperature ($T_{\alpha/\beta}$). Addition of Sc has prompted high temperature strength by 110 MPa for Ti–48Al alloy at 900 °C where the reinforcement compound formed being (Sc, Ti)$_3$Al of cubic structure with point group *Ia*3*d* and lattice constant $a = 0.984$ nm [15–17]. Introduction of Sc helped to decrease the transformation temperature of $\alpha \rightarrow \alpha_2 + \gamma$ and $\beta \rightarrow \alpha + \beta$ in Ti–40Al–16Nb alloy [18]. In aluminum alloys, Sc helped to refine microstructure leading to an increase in strength and recrystallization temperature by forming intermetallic phase of composition Al_3Sc [19–22]. Al_3Sc was coherent with the matrix resulting in significant strength increase. From Ti–Sc binary phase diagram (see Fig. 1), it is prospected that Sc should play a role of solid solution strengthening in Ti.

To our knowledge, the influence of Sc on the property of pure Ti has never been studied, and the work of Sc on multicomponent Ti alloy is limited too. How Sc affects the allotropic phase transformation of titanium alloys is not clear up to now. Therefore, we selected four compositions located in single α-Ti phase region and α-Ti + α-Sc two-phase region, respectively. The objectives of present work are to investigate: (i) as-cast microstructure and hardness of Ti–Sc binary alloys; (ii) microstructure evolution; (iii) thermodynamic description of phase transformation of Ti-based alloy, as function of Sc content.

2. Experimental methods

Commercial Ti (impurity content was Fe < 0.15%, C < 0.10%, N < 0.03%, H < 0.015%, O < 0.15%, balance was Ti) and Sc (purity 99.983%) were used to prepare pure Ti, Ti–2Sc, Ti–5Sc, Ti–25Sc and Ti–37Sc (wt%) alloys by vacuum arc melting technique where the button ingots were cooled in furnace to room temperature. The melting conditions

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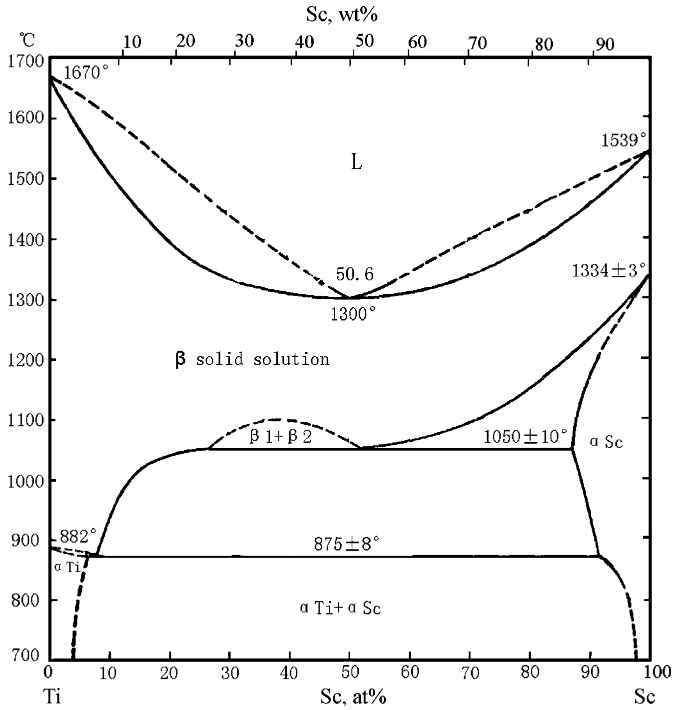

Fig. 1. Phase diagram of Ti–Sc binary alloy [23].

were as followings: water cooled copper crucible was used in a vacuum arc furnace, vacuum level was 1×10^{-3} Pa, the button ingots were turned over four times during melting. Heat treatments used for each alloy were listed in Table 1, the samples were put in quartz tube filled with Ar atmosphere, each sample was cut into several pieces which were annealed at three different temperatures, and quenched in water afterwards. The microstructure of as-cast and annealed samples, phases present in as-cast samples, phase transformation and hardness were examined by optical microscope (OM), X-ray diffraction (XRD) (Cu target, radiation $K_{\alpha 1}$, wave length 1.5406 Å), differential thermal analyzer (DTA) (N_2 atmosphere, reference sample material was Ni, crucible material was Al_2O_3, heating rate was 12 °C/min) and hardness tester (Vickers indenter, load 10 g, five indentations were treated on each samples, and the measured error is within 6.7%), respectively.

Table 1
Heat treatment of samples for 8 h

Alloy (wt%)	Temperature (°C)		
Ti–2Sc	750	850	950
Ti–5Sc	750	850	900
Ti–25Sc	800	950	1100
Ti–37Sc	800	950	1100

3. Results and discussion

3.1. Microstructure and hardness of as-cast alloys

Microstructures and hardness of as-cast Ti–Sc samples are shown in Fig. 2. Note, the size of α phase is much smaller in Ti–2Sc sample (Fig. 2b) with regard to pure titanium (Fig. 2a). The width of α lamellar has decreased from about 30 μm in Fig. 2a to a few microns in Fig. 2b [24]. The microstructure

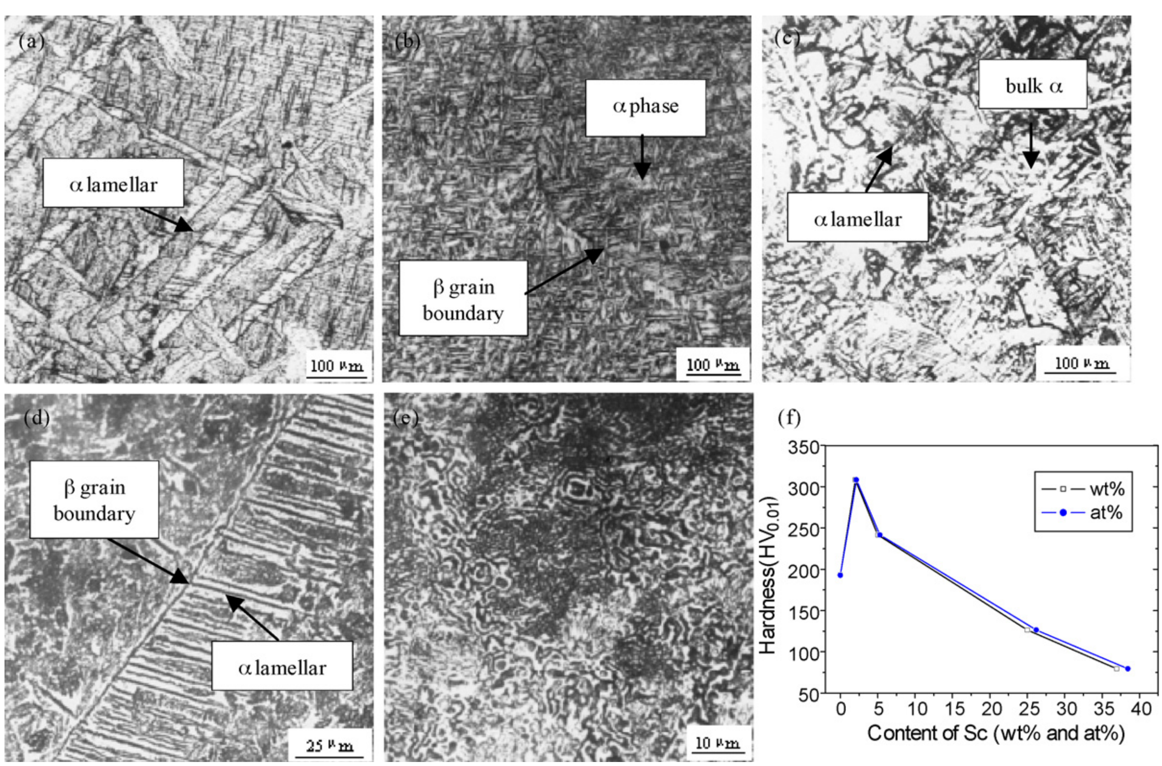

Fig. 2. As-cast optical microstructure and hardness of Ti–Sc alloy samples: (a) pure titanium, (b) Ti–2Sc alloy, (c) Ti–5Sc alloy, (d) Ti–25Sc alloy, (e) Ti–37Sc alloy, and (f) hardness.