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Effect of solid carburization on surface microstructure and hardness of Ti−6Al−4V alloy and $(TiB+La_2O_3)$/Ti−6Al−4V composite

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Abstract: Solid carburization was employed to improve the hardness of Ti−6Al−4V alloy and $(TiB+La_2O_3)$/Ti composite. The samples wrapped in graphite powder were placed in sealed quartz tubes, followed by solid carburization at 1227 K for 24 h. Microstructure and phase analysis indicated that TiC reinforcements and Ti−C solid solutions were introduced after solid carburization. Moreover, the volume fraction of equiaxed α-Ti phase in diffusion layer decreased obviously with increasing sample depth. Hardness testing results indicated that both the carburized surfaces performed significant improvement of about 100% in micro-hardness compared with untreated materials. The variation of carbon contents with increasing sample depth resulted in a hardened layer of 300 μm in the carburized samples. Meanwhile, slight influence on the internal microstructure and hardness indicated that solid carburization was an effective method in strengthening the surface of titanium alloy and titanium matrix composite.

Key words: titanium alloy; titanium matrix composite; solid carburization; microstructure; micro-hardness

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1 Introduction

Titanium and titanium alloys have been widely used in aerospace, chemical, biomedical industries due to their high specific strength and excellent corrosion resistance and biocompatibility [1]. Ceramic reinforcements with high elastic modulus and high strength are incorporated into titanium alloys to further improve the specific strength and stiffness [2]. Titanium matrix composites (TMCs) perform good combination of excellent mechanical properties and high temperature durability, which render them attractive materials for commercial automotive, aerospace and advanced military applications [3]. In situ synthesized discontinuously reinforced TMCs have drawn considerable interest due to strong interface bonding, good interfacial integrity, and cost-saving fabricating process [4]. The in situ synthesis methods mainly include self-propagation high temperature synthesis (SHS) [5], powder metallurgy (PM) [6], mechanical alloying (MA) [7], rapid solidification process (RSP) [8], ingot metallurgy (IM) [9], etc. However, low fracture ductility of TMCs with high volume fraction of reinforcements seriously restricts the practical application compared with monolithic titanium and titanium alloys [10,11]. On the contrary, ductile titanium alloys and TMCs with low volume fraction of reinforcements show unsatisfactory wear resistance such as high friction coefficient and low hardness [12,13]. Therefore, lots of surface modification methods have been proposed to strengthen the surface of titanium alloys and titanium matrix composites.

Common surface engineering methods can be divided into three main groups: heat treatment, coatings and thermochemical treatment [14,15]. The most attractive method, thermochemical treatment, includes laser carburizing and nitriding, plasma carburizing, plasma alloying, gas carburizing, gas nitriding and glow discharge methods [16−18]. The diffusion treatment techniques significantly strengthen the surface by introducing a hardened layer, which is composed of solid solutions and ceramic particles due to implantation of carbon and nitrogen into the titanium alloys respectively [17−19]. As discussed in Refs. [20,21], the carburized layer was formed on the surface of Ti−6Al−4V alloy and TiAl alloy by plasma carburizing.

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Significant improvement in surface hardness and wear resistance could be attributed to various carbide particles in the carburized layer. Laser surface alloying [22] and cladding [23] were employed to strengthen the surface of pure Ti and Ti−6Al−4V alloy. Significant increase in hardness and wear resistance was observed compared with untreated materials due to the introduction of TiC phase. WU et al [24] investigated the effects of molten salt carburization parameters on the surface hardness and tribological properties of Ti−6Al−4V alloy. The result indicated that major hardening effect was considered to be the formation of solid solution of carbon in α-Ti. However, the major limitation of above carburizing methods in application is the problem of high cost and complicated equipment. Meanwhile, most previous researches focus on pure titanium and Ti−6Al−4V alloy. Further research of simple carburization technology on TMCs is still required due to their attractive mechanical properties of high specific strength and stiffness.

In this study, solid vacuum carburization on Ti−6Al−4V alloy and (TiB+La_2O_3)/Ti−6Al−4V composite was carried out to improve the surface hardness without affecting the internal microstructure. The (TiB+La_2O_3)/Ti−6Al−4V composite with low volume fraction of reinforcements was selected because TiB was considered to be the best reinforcement and lanthanum element could reduce the oxygen content in the matrix alloy [9]. Graphite powder was employed as carbon supply to avoid hydrogen brittleness. The constituent phases in the carburized layer were determined by X-ray diffraction. Microstructure and micro-hardness were analyzed to evaluate the reaction and diffusion behavior of Ti−6Al−4V alloy and (TiB+La_2O_3)/Ti−6Al−4V composite during solid carburization.

2 Experimental

2.1 Materials

Forged Ti−6Al−4V alloy and (TiB+La_2O_3)/Ti−6Al−4V composite were used as experimental materials. Figure 1 shows the different original microstructures of the two untreated experimental samples. Figure 1(a) shows the uniform duplex microstructure of Ti−6Al−4V alloy, which is composed of equiaxed α phase and lamellar α phase. The size of equiaxed α phase is about 10 μm, while the thickness of lamellar α phase is only several hundred nanometers. Figure 1(b) shows the microstructure of (TiB+La_2O_3)/Ti−6Al−4V composite. It can be observed that TiB whiskers with the length of 5−10 μm are distributed homogeneously in the lamellar microstructure matrix alloy.

2.2 Solid carburization

Ti−6Al−4V alloy and (TiB+La_2O_3)/Ti−6Al−4V composite samples with dimensions of 10 mm × 10 mm× 3 mm were prepared by wire cutting. The polished samples wrapped in graphite powder were placed in quartz tubes respectively. The quartz tubes were sealed in argon to keep the samples from being oxidized at high temperatures. Solid vacuum carburization was carried out in a box type electric resistance furnace at 1227 K for 24 h. Figure 2 shows the schematic diagram of the solid vacuum carburization process. The carburized samples were taken out after cooling down to room temperature in the heat treatment furnace.

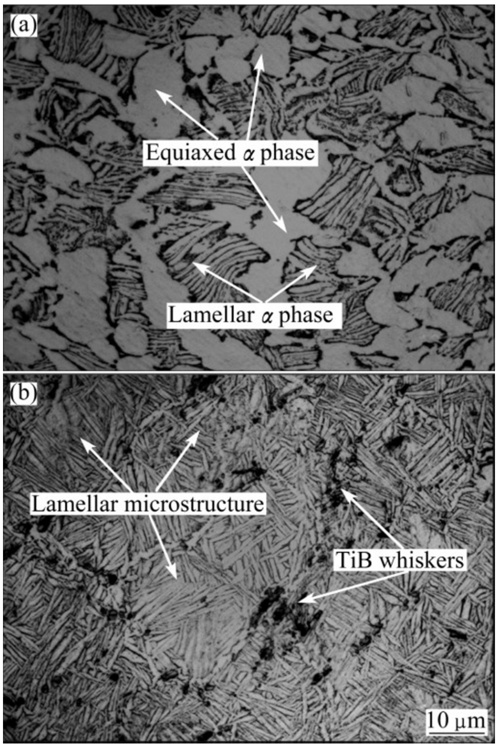

Fig. 1 Original microstructures of experimental samples: (a) Ti−6Al−4V alloy; (b) (TiB+La_2O_3)/Ti−6Al−4V composite

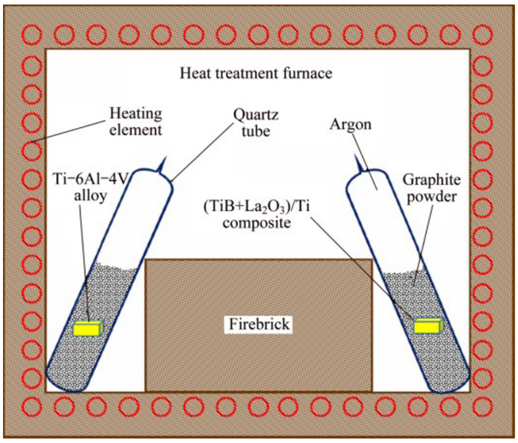

Fig. 2 Schematic diagram of solid vacuum carburization process