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Short Communication

Effects of hydrogen on the interfacial reaction between Ti–6Al–4V alloy melt and Al_2O_3 ceramic shell

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ABSTRACT

Effects of hydrogen on the interfacial reaction between Ti–6Al–4V (Ti64) alloy melt and Al_2O_3 ceramic shell were studied by arc-melting in H_2/Ar gaseous mixture. The thickness of interfacial reaction layer between Ti64 alloy melt and Al_2O_3 ceramic shell without hydrogenation is 80 μm. But the thickness of reaction layer can be reduced to 10 μm at a hydrogen partial pressure of 20 kPa, which is better than the thickness of interface layer between Ti64 alloy and widely used Y_2O_3 shells. At Ti64 casting surface, the content of β-soft ductile phase is increased and the width of both reaction zone and transition zone are reduced with the increase of hydrogen partial pressure, thus reduces the hardness and the element diffusion distance. Therefore, Hydrogen can effectively control the interfacial reaction in the process of titanium alloy investment casting, and Al_2O_3 ceramic will be a kind of very promising shell material.

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Introduction

Titanium alloys have superior performance such as high specific strength, high specific stiffness, good corrosion resistance and biocompatibility [1,2]. However, titanium alloy has low ductility and poor workability at room temperature, and the high temperature deformation resistance is large [3,4]. In order to solve poor formability and high machining cost problems, the near net shaping technology, especially investment casting technology has been widely used [5]. However, a chief obstacle to the use of investment casting is titanium alloy has high reactivity in the molten state. They can react with oxygen and almost all the molding materials during investment casting, resulting in an oxygen-enriched interfacial reaction layer [6]. The layer affects the mechanical properties such as ductility, toughness and hardness of the titanium alloy casting [7,8]. Therefore, a special requirement

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for molding materials is to form a thinner reaction layer with titanium alloy melt.

At present, Y_2O_3 and ZrO_2 shells as molding materials have been studied in the investment casting due to a relatively high stability with titanium alloy melt [9,10]. But Y_2O_3 and ZrO_2 shells are expensive, so the use of Y_2O_3 and ZrO_2 shells is very limited. In terms of price, Al_2O_3 ceramic is a kind of very promising shell material [11], and Chen et al. [12] have studied Al_2O_3 casting mold in titanium investment casting. Based on their research, Al_2O_3 ceramic shell has poor stability with titanium alloy melt, and the interfacial reaction is very severe, so a thick layer is formed on the surface of titanium alloy castings. These researchers, however, just concentrate on the interface between titanium alloys and various types of mold materials, but not propose a simple method that can reduce the thickness of the interfacial reaction layer. Therefore, an effective and practical method to inhibit its reactions has been needed.

Hydrogen may play a role in controlling the interfacial reaction between titanium alloys and molding materials. It is generally known that titanium alloys have a high affinity for hydrogen and may cause embrittlement [13–15]. But the latest research proved that hydrogen has many positive effects [16–19]. It can refine grain, increase the content of soft β ductile phase at room temperature and produce purification effect on titanium alloy melt. And hydrogen can be easily removed by vacuum annealing [20]. So, if hydrogen has positive effect on controlling the interfacial reaction, it will improve the quality of casting surface, reduce the thickness of interfacial reaction layer, and reduce the cost of casting materials. Thus the study is of broad significance.

In this study, most widely used α+β alloy, Ti–6Al–4V (Ti64) alloy [21,22] and very economical shell material Al_2O_3 ceramic were chosen as casting materials and molding materials respectively. The aim of this study is to introduce hydrogen to Ti64 alloy melt and reduce thickness of the interface layer. We investigated the effects of hydrogen on interface layer between Ti64 alloy and Al_2O_3 ceramic shell and discussed the mechanism.

Materials and methods

The Ti64 alloy used in this experiment was 30 mm diameter rod, of which the chemical compositions is (in weight percent) 6.26% Al, 4.13% V, 0.14% O, 0.07% Si, 0.03% N and the balance is Ti.

The procedure of making Al_2O_3 ceramic shell are as follow. The wax mold has simplest rectangular structure. It was dipped in ceramic coating, which was mixed by 75 wt % white corundum powder (325 mesh) and 25 wt % silica sol. After taking out, the white corundum powder (80 mesh) was evenly dispersed on the surface of the coating. Then put the mold into air and dried. The above steps were repeated for 6 times. The mold was dewaxed by roasting at 200 °C for 2 h. The Al_2O_3 ceramic shell was ready after sintered the mold at 1000 °C for 2 h.

The Ti64 alloys were melted by arc melting in a water-cooled copper crucible under 0.05 MPa H_2/Ar gaseous mixture. Five different hydrogen partial pressures were selected as 0, 5, 10, 15 and 20 kPa. The hydrogen absorbed by the Ti64 alloy can be determined according to our previous study [16], under 5 kPa, 10 kPa, 15 kPa, 20 kPa hydrogen partial pressures, the relative hydrogen content in Ti64 alloy were 3.64×10^{-2} wt.%, 6.15×10^{-2} wt.%, 8.25×10^{-2} wt.%, 9.12×10^{-2} wt.% respectively. Our study mainly focus on the casting process, so the work is still use the hydrogen partial pressure to discuss and analysis. To minimize the experimental uncertainties like melting temperature, each sample were melted with same time and current. When hydrogen was saturated in the alloy melt, pour the alloy melt from the crucible into a mold shell. Then cut a 10 mm × 10 mm × 10 mm block from the reaction interface.

Microstructure and chemical compositions were identified using 200F scanning electron microscope (SEM) equipped with energy disperse spectroscopy (EDS). The metallographic structure was studied using Olympus - GX71 metallographic microscope. Vickers micro hardness measurement was conducted by HVS-50 digital Vickers hardness tester with 9.806 N test force and 10s loading time.

Results

Effects of hydrogen on interface layer thickness

In the process of ceramic shell mold contacting with the alloy melt, due to high temperature and scour effect of alloy melt, the alloy melt will penetrate into ceramic mold surface layer, then form a transition layer between the alloy melt and the mold shell surface. Fig. 1a shows the microstructure of interface layer between Ti64 alloy melt and Al_2O_3 ceramic shell without hydrogenation. It is clear that the interface layer has rough surface, with some cracks, pores and other defects exist, which have great impact on the performance of castings. The size of ceramic particles are different because ceramic particles will dissolute when moving to the internal alloy melt. According to Fig. 1a, the thickness of the interfacial reaction layer between Ti64 alloy melt and Al_2O_3 ceramic shell without hydrogenation is about 80 μm.

Table 1 shows the chemical compositions of point A and point B in Fig. 1. The EDS results indicate that the chemical composition of point A is close to Ti–6Al–4V, the content of Al element, O element, Si element is increased and the content of Ti element is reduced compared to Ti–6Al–4V. The chemical composition of point B is close to Al_2O_3, and the content of O element is reduced compared to Al_2O_3. Therefore, we speculate the white region is Ti64 alloy matrix, and those black blocks and granules are Al_2O_3 ceramic particles. There are two main reasons to explain the change of element content. Firstly, XRD results of interface layer are showing in Fig. 1b. After interfacial reaction, new compounds like Ti_3O, Ti_6O are formed in the surface layer, but there is no Al_2SiO_5 and SiO_2 phase, which means when Ti64 alloy melt contact with ceramic shell mold surface, the stability of titanium sub oxide is higher than the stability of SiO_2, therefore Ti element can substitute Si element, which promoted the elements diffusion between alloy matrix and shell mold. Secondly, the ceramic particles will dissolute when ceramic particles moving to the internal alloy melt, and the ceramic phase

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