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Application of thermohydrogen processing to Ti6Al4V alloy blade isothermal forging

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ABSTRACT

Application of thermohydrogen processing to Ti6Al4V alloy blade isothermal forging is researched in this paper. The basic properties relating to hot workability of unhydrogenated and hydrogenated with 0.25 wt%H Ti6Al4V alloys are investigated. Isothermal compression tests are used for getting the stress–strain relationship under different forming temperature, and the mechanism of hydrogenation inducing Ti6Al4V alloy softening is researched. The billet shape is optimized by DEFORM-3D software, then force and flow condition are analyzed in the isothermal forging process. The results show that the qualified blades can be forged under the isothermal forging conditions of 0.1 mm/s, 1223 K for unhydrogenated alloy and 1123 K for hydrogenated alloy. After vacuum heat treatment at 973 K for 4 h, the experiment's results of mechanical properties show that thermohydrogen processing improves the mechanical properties of the blade at both room and high temperature.

1. Introduction

Ti6Al4V alloy is widely used in aerospace industry, especially as a suitable material for aero engine blades, because of high specific strength, hot strength and good corrosion resistance [1,2]. Nowadays, isothermal forging is a key technology for making advanced aero engine, especially in the manufacture process of blades [3]. In isothermal forging process of titanium alloy blade, the deformation and wear of the die are serious, because titanium alloy has a high deformation resistance and temperature, about 1223 K [4,5]. Ni-base superalloy is widely used for die material in isothermal forging of titanium alloy, which is apt to deform and wear at high temperature and load, leading to the decrease of dimensional accuracy and die life [6,7], so dimensional accuracy of blades cannot be guaranteed in batch manufacturing. The decrease of deformation resistance and temperature are very important for reducing the wear and deformation of die, and lead to the improvement of die life and blade quality.

Thermohydrogen processing of titanium alloy, in which hydrogen is used as a temporary alloying element, is a new technology for improving the hot workability of titanium alloy through changing microstructure [8,9]. Some reports show that [10–14], compared with normal forging, thermohydrogen processing can reduce the forging load by around 70% at the same conditions, which is equivalent to decreasing the forming temperature by 100–150 K. It is important for the improvement of die wear and dimensional accuracy of blade. For example, K403 nickel-base superalloy (chemical composition of K403 alloy: 0.15%C, 10.79%Cr, 5.22%Co, 5.06%W, 4.10%Mo, 5.58%Al, 2.58%Ti, 0.018%B, 0.05%Zr, Bal.Ni) is usually used as a die material for the forging of titanium alloy. When the temperature reduces from 1173 K to 1073 K, its tensile strength and creep limit increase by around 25% and 90%, respectively. So die life and blade quality can be improved through the decrease of deformation resistance and temperature with the application of thermohydrogen processing.

In this paper, thermohydrogen processing is tried to produce Ti6Al4V alloy blade. Microstructure and mechanical properties of blade affected by forging and vacuum heat treatment process is researched.

2. Materials and methods

2.1. Materials

The chemical compositions of Ti6Al4V alloy used in this paper are shown in Table 1.

According to phase transformations in Ti6Al4V-H systems [15,16], the hydrogenation process is carried out in the special furnace in hydrogen atmosphere. The hydrogenation process of specimens is as follows: making vacuum → adding argon → heating to 1023 K → adding hydrogen → insulation for 2 h → furnace cooling to room temperature.

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Table 1
The chemical compositions of Ti6Al4V alloy.

Element	Al	V	Fe	C	N	O	H	Ti
wt%	6.29	4.11	0.05	0.008	0.03	0.13	0.004	Bal.

The hydrogen content of specimens is controlled through equilibrium partial pressure, and then measured by Sartorius BT125D electronic balance with an accuracy of 0.01 mg.

Thermogravimetry analysis (TGA) is performed by using a Mettler Toledo TGA/SDTA851 in the temperature range 300–1773 K in an argon atmosphere with a heating rate of 10 K/min.

2.2. Methods

Compression and tensile tests are carried out on an Instron 5500 machine, and a resistance furnace with an accuracy of 1 K can be used for heating during the processes of high temperature (673 K) tests. Impact tests are carried out on Instron 9250 HV machine.

The blades isothermal forging are carried out on hydraulic press with the maximum load of 6300 kN, which allocates a resistance furnace with an accuracy of 1 K. The hydraulic press and furnace for blades forging are presented in Fig. 1. Before forging, the billets must be sandblasted and sprayed by glass lubricant.

Vacuum heat treatment is carried in a quartz tube vacuum furnace with the maximum vacuum degree of 5×10^{-4} Pa.

The microstructures are examined by OLYMPUS GX71 optical microscopy and Philips-CM12 transmission electron microscopy (TEM).

3. Results and discussion

3.1. TGA and isothermal hot compression tests

A method based on TGA for studying phase transition process of titanium alloys is proposed in reference [17],and according to that the TGA curves of unhydrogenated and hydrogenated with 0.25 wt%H Ti6Al4V are shown in Fig. 2. It can be seen that, the $\alpha+\beta$ phase region of unhydrogenated Ti6Al4V alloy ranges from about 960 K–1241 K, and the $\alpha+\beta$ phase region of 0.25 wt% hydrogenated Ti6Al4V alloy lies approximately between 960 K and 1143 K. The mass of hydrogenated Ti6Al4V alloy begins to decrease at 640 k, and then decreases sharply at 960 K. So the dehydrogenation temperature should be higher than 960 K, and 973 K is chosen in this work.

Isothermal hot compression tests are cylinders of 8 mm in diameter and 12 mm in height and carried out with the deformation

Fig. 1. The hydraulic press and furnace for blades forging.

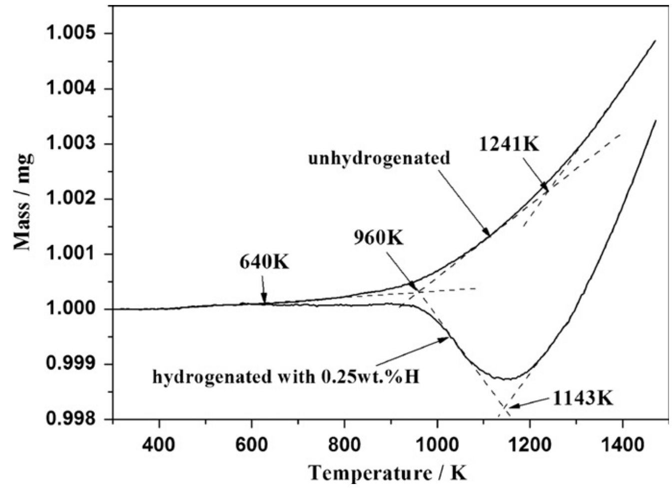

Fig. 2. the TGA curves of unhydrogenated and hydrogenated with 0.25 wt% Ti6Al4V.

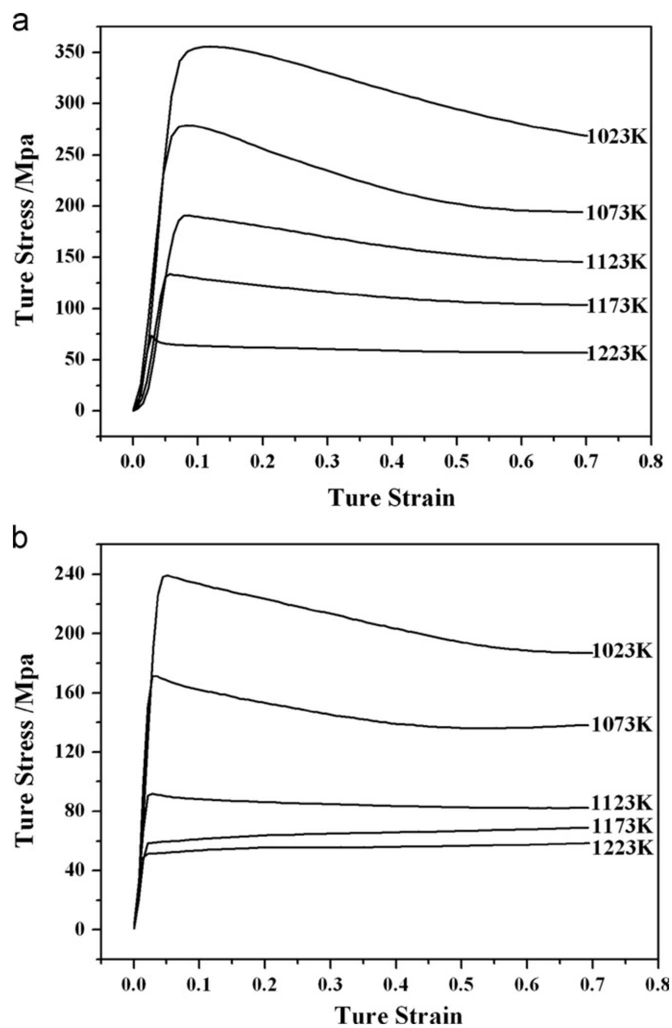

Fig. 3. Stress–strain curves of (a) unhydrogenated and (b) 0.25 wt%H hydrogenated Ti6Al4V alloy at 0.1 mm/s.

rate of 0.1 mm/s at the temperatures of 1023 K, 1073 K, 1123 K, 1173 K and 1223 K. Glass lubricant is coated at the two ends of the specimens. The specimens are held at compression temperature for 3 min and subsequently deformed until deformation extent reached