



Effects of electric pulse heat treatment on microstructures and dynamic deformation behaviors of Ti6441 alloys

Dongmei Huo^{a,b}, Shukui Li^{a,b}, Qunbo Fan^{a,b,*}, Fuchi Wang^{a,b}

^a School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, China

^b National Key Laboratory of Science and Technology on Materials Under Shock and Impact, Beijing 100081, China

ARTICLE INFO

Article history:

Received 27 July 2011

Received in revised form

14 September 2011

Accepted 15 September 2011

Available online 21 September 2011

Keywords:

Titanium alloy

Electric pulse heat treatment

Microstructure

Mechanical characterization

Shear bands

ABSTRACT

With respect to a newly developed titanium alloy Ti–6Al–4V–4Zr–Mo (Ti6441), electric pulse heat (EPH) treatment is innovatively employed to modulate lamellar microstructure details. It is interesting to find that, without mechanical processing such as forging, the EPH treatment can significantly decrease the prior beta grains size down to 390 μm from its original size of 520 μm . Further microstructure analyses show that alpha colonies, as well as alpha plates, are also refined correspondingly. The refinement behaviors are contributed by the unique effects of electric pulses, such as the acceleration of nucleation rate and the retard of grain growth. Especially, the EPH treatment has the orientation of alpha colonies tailored to be regularly 60°-intersected, different from the irregularly oriented lamellar structure treated by conventional heat-treatment furnace. Dynamic compression test results show that the fracture strain of the EPH-treated specimen is obviously increased from 23% to 29%, owing to the attenuation of local stress concentration, and the fracture strength retains a fairly high level. According to the forced shearing experiment results, the susceptibility to the adiabatic shear bands (ASBs) of the Ti6441 alloy after the EPH treatment is declined, because of the apparent ASBs' deflection and bifurcation.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Titanium and titanium alloys are widely used for military purposes, e.g. recent applications for armor materials of combat vehicles, due to their excellent properties such as low density and high specific strength [1–3]. One of the most important aspects on the investigation of titanium alloys is microstructure characteristics, because the mechanical properties of these alloys are strongly dependent on their microstructures, which are mainly divided into lamellar, bimodal and equiaxed ones according to heat treatment and thermo mechanical processing [4,5]. Among them, the lamellar microstructure is known to have preferable specific strength, fracture toughness, creep resistance and resistance to crack propagation, but lower ductility, due to the fact that the lamellar microstructure has relatively larger prior beta grains size [6–8]. Therefore, in order to obtain desired mechanical properties, the detailed microstructure parameters, such as prior beta grains size, alpha colonies size and thickness of alpha plates, of

titanium alloys with lamellar microstructures, and the relationship between microstructure characteristics and mechanical properties have been extensively studied. Lee et al. [9] investigated the effects of lamellar microstructure parameters on the dynamic torsional deformation behaviors of Ti–6Al–4V alloys. They reported that the possibility of adiabatic shear bands (ASBs) formation in the microstructure with alpha colonies and alpha plates both in large size was the highest. Besides, Lütjering [6] and Bhattacharjee et al. [10] pointed that the decrease in the thickness of alpha plates generally resulted in an increase in the yield stress and quasi-static tensile ductility. Besides, the size of prior beta grains is an important parameter of lamellar microstructure characteristics. Many researchers [11–13] have focused on determining the prior beta grains size and mechanical property relationships. They claimed that the coarse grain caused negative effects on yield strength and ductility. However, the large prior beta grains size could not be avoided merely by heat treatment using a conventional furnace [13].

Recently, electric pulse heat (EPH) treatment is known as an effective method to improve the properties of metallic materials, and one of the most interesting research results points out that, with rapid heating and subsequent fast cooling methods during EPH treatment process, small grains can be obtained [14–17]. Valeev and Kamalov [14] studied the features of structure formation and

* Corresponding author at: School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, China. Tel.: +86 010 68911144; fax: +86 010 68911144x869.

E-mail address: fanqunbo@bit.edu.cn (Q. Fan).

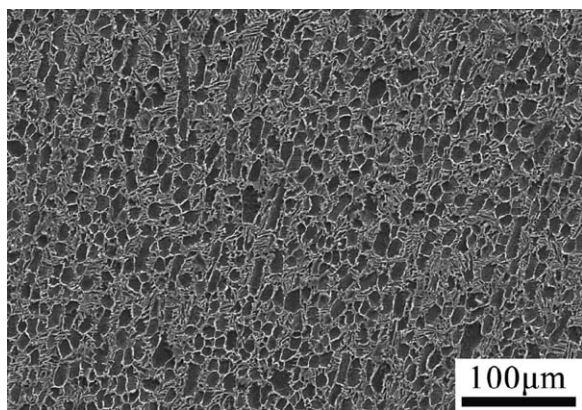


Fig. 1. SEM micrographs of the Ti6441 alloys in as-received state.

changes in micro hardness of pre-deformed copper. They concluded that the action of electric pulses lead to grain refinement and thus resulted in the increase of micro hardness. Unfortunately, little information has been reported for utilizing electric pulse heat treatment to vary the detailed microstructure characteristics of titanium alloys with lamellar microstructures.

The objective of the present work, therefore, is to modulate the lamellar microstructure details of titanium alloy by using EPH treatment, thus improving its dynamic mechanical properties. The material used in this study is Ti–6Al–4V–4Zr–Mo (Ti6441), a newly developed titanium alloy at Beijing Institute of Technology. Effects of microstructure characteristics (before and after EPH treatment) on dynamic compression and forced shearing behaviors are investigated.

2. Materials and methods

The beta-transus temperature of Ti6441 alloy was determined at 945 °C. The typical microstructure of the alloy in as-received state was consisted of equiaxed grains with uniform size, as shown in Fig. 1, which was produced via alpha + beta processing route, i.e. initial forging in the beta phase region and final forging in the alpha + beta phase region.

As shown in Table 1, starting from the globular as-received state, the Ti6441 alloys were heat treated in a conventional heat-treatment furnace above the beta-transus temperature (at 960 °C) for 1 h, followed by air cooling to obtain typical lamellar microstructures, named L0. Then, the EPH treatment was performed on the L0 microstructure by heating to 1020 °C at a high temperature rising rate of 100 °C/min, then soaking for 10 min, followed by air cooling to room temperature to obtain a new lamellar microstructure, named LP. The metallographic analyses were made by optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). In order to facilitate distinguishing the primary alpha and beta phases in the SEM micrographs, Image-Pro Plus 6.0 was used to improve the image contrast. Both the average size of prior beta grains and alpha plates were calculated by using the Image-Pro Plus 6.0.

The dynamic compression tests and forced shearing tests were performed by a Split Hopkinson Pressure Bar (SHPB) system. The geometrical shape and size of specimens were shown in Fig. 2.

Table 1
Heat treatment parameters for the Ti6441 alloys.

Specimens no.	Heat treatment
L0	960 °C/1 h/AC
LP	960 °C/1 h/AC + EPH 1020 °C/10 min/AC

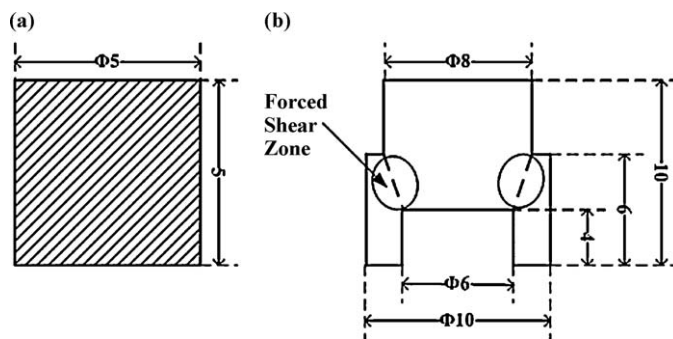


Fig. 2. Geometrical shape and size of the (a) cylindrical specimens and (b) hat specimens for dynamic mechanical properties tests and forced shear tests, respectively (unit: mm).

Dynamic compression tests were conducted on cylindrical specimens with a diameter of 5 mm and a height of 5 mm, as illustrated in Fig. 2 (a). By data acquisition system, the original pulses of incident, reflected and transmitted waves were recorded. Then, true dynamic compress stress–strain curves at a high strain rate condition were obtained by calculating the stress, strain and strain rate from the original pulses. To investigate the dynamic deformation behaviors of Ti6441 alloys, the critical fracture strain, i.e. the finishing point of uniform plastic deformation, was defined when the flow stress fell to 90% of the maximum stress and indicated by arrows in the dynamic stress–strain curves. The fracture surfaces of the specimens after dynamic compression tests were observed using the SEM. Forced shearing tests were carried out on hat-shaped specimens (Fig. 2(b)) with a height of 10 mm and a maximum diameter of 10 mm. Due to the specimen's special hat-like shape, the adiabatic shear deformation was forced to occur in a narrow region. By data acquisition, a voltage–time curve at a certain strain rate was obtained and the voltage value was proportional to the applied load. The curves recorded the entire response time of the samples, from the very initial stage when subject to the dynamic load to the formation of ASBs, followed by final fracture. If the specimens underwent adiabatic shear failure, the bearing time would be $\leq 80 \mu\text{s}$ (the loading time of incident pulses in the current work). Thus, the susceptibility to the ASBs of specimens with different lamellar characteristic parameters before and after the EPH treatment could be characterized using the voltage–time curves at a certain strain rate. The ASBs within the specimens were further examined by SEM and TEM.

3. Results and discussion

3.1. Microstructures before and after EPH treatment

3.1.1. Prior beta grains

The L0 and LP microstructures of the Ti6441 alloys observed by the OM are shown in Fig. 3(a) and (b), respectively. It can be seen from Fig. 3(a) that the typical beta-annealed lamellar microstructure, L0, is composed of thin lath-type alpha and beta plates, and the coarse-grained lamellar microstructure is divided into colonies of lamellae packages with different orientation angles. As calculated by the Image-Pro Plus 6.0, the coarse-grained L0 microstructure has an average prior beta grains size of 520 μm . In contrast, significant refinement is induced under EPH treatment, as shown in Fig. 3(b). After EPH treatment, the LP microstructure consists of smaller prior beta grains with an average size of 390 μm .

Metallographic analysis reveals that lamellar microstructure of Ti6441 alloy undergoing a subsequent EPH treatment performs refinement behavior and it is amazing that the present refinement of prior beta grains is achieved merely by EPH treatment,

Download English Version:

<https://daneshyari.com/en/article/1577973>

Download Persian Version:

<https://daneshyari.com/article/1577973>

[Daneshyari.com](https://daneshyari.com)